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Determinations of Proper Motions by using the Astrographic Catalogue

By MIRIAM E. WALTHER

Many years have elapsed since astronomers from all over the world met in Paris to launch one of the most ambitious enterprises in the history of astronomy. Here were formulated elaborate plans for the Astrographic Charts and Catalogue which would give the positions of stars approximately as faint as 12th magnitude for the entire sky. Accurate positions of stars had been catalogued for more than two centuries from visual observations. The quality of these positions could hardly be surpassed, but meridian observations could not compete with the revolutionary methods of photography in the production of very extensive catalogues. For years volume after volume of the Astrographic Catalogue has accumulated in observatory libraries, often without being used at all. But now fifty years have elapsed since some of the first astrographic plates were taken, an ample interval for determining accurate proper motions. The catalogue is especially valuable since it reaches to the 12th magnitude, much beyond the Astronomische Gesellschaft Catalogue or the Boss General Catalogue. A number of worthwhile proper motion programs might well be undertaken at observatories with telescopes of intermediate size. The proper motions of faint stars can be determined simply by comparing the positions on recent photographic plates with the positions of stars given in the Astrographic Catalogue. Dr. A. N. Vyssotsky at the McCormick Observatory has used this method recently in determining the motions of more than 70 M-dwarfs. Previously Luyten (see *H. C.* 293 and *H. B.* 900) had used the Astrographic Catalogue for determining proper motions. The value of the method lies in the fact that the proper motions of faint stars can be determined without the observer having to wait several years to obtain a second plate. In brief, the procedure consists of reducing a portion of the plate of the Astrographic Catalogue to the recent plate and then comparing the two sets of positions.

The procedure involves the computation of plate constants which may be evaluated simply by applying the method of Christie and Dyson.[1] These authors use the method of averages, but in their article they only indicate the procedure. Furthermore, Smart's[2] treatment of the subject idealizes the procedure. As far as the writer knows, no detailed exposition of this useful method has been published previously.

Hence it seems desirable to give it here more fully, and to illustrate it with an actual example.

As far as is possible the reference stars should be selected so that the proper motion star lies approximately near their geometrical center. If no great accuracy is required, it is sufficient to choose only four reference stars; otherwise more stars can be selected in each quadrant, and the mean position taken of the group lying in each quadrant. We may suppose the positions of the four reference stars and of the star S whose motion is to be investigated as shown in Figure 1, where the origin is at the geometrical center.

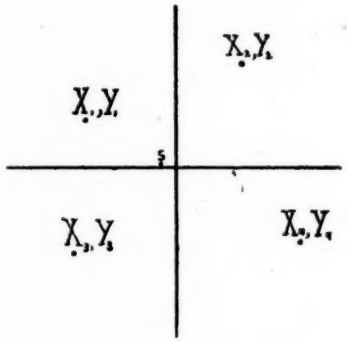

FIGURE 1

Let (X_1, Y_1), (X_2, Y_2), etc., denote the measured coordinates of the images on the old plates, and X_1', $Y'_1)$, (X_2', Y_2'), etc., those on the recent plate. Then, as is well known, the difference

$$X_1' - X_1 = \Delta X_1$$

can be represented by the linear equation

$$aX + bY + c = \Delta X$$

where a and b are respectively the constants which determine the relative scale and orientation, and c is the zero-point difference. This method assumes that the motions of the reference stars are small and that they may be neglected. In case of stars in high latitudes, where the motions of the reference stars may be large, the constants are determined less accurately. The equations for the four stars become:

$$aX_1 + bY_1 + c = \Delta X_1$$
$$aX_2 + bY_2 + c = \Delta X_2, \text{ etc.}$$

where a and b are reduced to a minimum by orienting the two plates in the same way and adjusting the values of the scales of the two plates through multiplication by the proper factor. Adding these four equations, we see that the coefficients of a and b vanish since by our choice

of origin

$$\sum_1^4 X_i = 0 \text{ and } \sum_1^4 Y_i = 0;$$

hence we have

$$4c = \sum_1^4 \Delta X_i \text{ or } c = (\sum_1^4 \Delta X_i)/4 \quad \text{(i)}$$

The equations of the four stars become then:

$$\begin{aligned} aX_1 + bY_1 &= \delta X_1 \quad (1)\\ aX_2 + bY_2 &= \delta X_2 \quad (2)\\ aX_3 + bY_3 &= \delta X_3 \quad (3)\\ aX_4 + bY_4 &= \delta X_4 \quad (4) \end{aligned}$$

where

$$\delta X_i = \Delta X_i - c. \quad (5)$$

Christie and Dyson have found empirically that a determination of *a* and *b* very close to that found by using the method of least squares may be obtained if the equations are combined in the following manner.

Subtracting the sum of equations (1) and (3) from the sum of equations (2) and (4) we have:

$$a\,(-X_1+X_2-X_3+X_4) + b\,(-Y_1+Y_2-Y_3+Y_4) = -\delta X_1+\delta X_2-\delta X_3+\delta X_4 \quad (6)$$

Similarly, subtracting the sum of (3) and (4) from the sum of (1) and (2):

$$a\,(X_1+X_2-X_3-X_4) + b(Y_1+Y_2-Y_2-Y_4) = \delta X_1+\delta X_2-\delta X_3-\delta X_4 \quad (6')$$

The equations (6) and (6′) can now be solved as simultaneous equations. Corresponding equations may now be written for the motions in Y in the form

$$eX + dY + f = \Delta Y,$$

and values of *f*, *e*, and *d* may be determined similarly.

In order to clarify the procedure an example with most of the details is given below.

AC + 49° 2493 — 285

Plates: AC (Catania Zone) September 13, 1904
McCormick π 52597 September 12, 1943

TABLE I

POSITIONS FROM ASTROGRAPHIC CATALOGUE

No.	x	y	2.89 x	2.89 y
240	— 4.9797	+11.1409	—14.391	+32.197
241	— 4.0381	+26.2266	—11.670	+75.795
285	+ 5.2497	+20.5277	+15.172	+59.325
312	+15.2766	+32.6618	+44.149	+94.393
336	+21.7233	+11.4451	+62.780	+33.076

TABLE II

No.	x'	2.89 x+80.5	McC-Cat ΔX	y'	2.89 y+63.0	McC-Cat ΔY
240	66.262	66.109	+.153	95.622	95.197	+.425
241	69.038	68.830	+.208	139.235	138.795	+.440
285	96.198	95.672	+.526	122.668	122.325	+.343
312	124.873	124.649	+.224	157.831	157.393	+.438
336	143.459	143.280	+.179	96.490	96.076	+.414

TABLE III

Quadrant	No.	X	Y	δX	δY	−aX−bY	r	−eX−dY	r'
3	240	−34.6	−26.7	−.038	−.004	+.031	−.007	+.005	+.001
1	241	−31.9	+16.9	+.017	+.011	−.009	+.008	−.008	+.003
	285	− 5.0	+ 0.5	+.335	−.086	.000	+.335	.000	−.086
2	312	+23.9	+35.5	+.033	+.009	−.037	−.004	−.009	.000
4	336	+42.6	−25.8	−.012	−.015	+.015	+.003	+.012	−.003

The primary criterion for selecting the reference stars is that they be distributed so that their mean position nearly coincides with that of the star whose proper motion is to be determined. If high accuracy is desired it is preferable to select stars of spectral types A and K since these stars are known to have relatively small proper motions. In high latitudes where the number of stars in the field is very small it may be necessary to disregard this consideration.

In the example, the proper motion of AC +49° 2493-285 has been determined by comparing the measures from the Catania Zone with a McCormick plate. The observed coordinates of the reference stars, x and y as given in the Astrographic Catalogue, are recorded as shown in columns 2 and 3 of Table I. From information in the catalogue the necessary factor can easily be determined to adjust these coordinates to approximately the same scale as that of the recent plate which is used for comparison. The scale of the AC plates is $60'' = 1$ mm., while that of the McCormick plates is $20''.75 = 1$ mm. Therefore in order to reduce the scale of the Catania plate to that of McCormick, we multiply columns 2 and 3 by $(60''/20''.75) = 2.89$. This reduces the size of the plate constants a and e which take care of the remaining difference in scale between the two sets of coordinates. The new coordinates are listed in columns 4 and 5 of Table I. As a check on the identification of the reference stars, these latter coordinates when plotted on millimeter paper should nearly coincide with the images on the recent plate.

The McCormick plate may now be measured, the orientation being accomplished by making the differences in the scale readings agree approximately with those from columns 4 and 5 of Table I. The positions are recorded in columns 2 and 5 of Table II; the Catania coordinates, increased by a constant amount to agree approximately with the McCormick measures, are listed in columns 3 and 6. Columns 4 and 7 contain the differences between the two sets of coordinates from which we immediately determine the constants c and f as +.191 and +.429, respectively [*cf.* equation (i)]. Subtracting these constants from ΔX

and ΔY, respectively, we obtain the values of δX and δY listed in columns 5 and 6 of Table III.

Figure 1 has been drawn to illustrate this particular example. Here

$$X_1 = 2.89x_1 - 20.2$$
$$Y_1 = 2.89y_1 - 58.8$$

Thus they are now referred to the geometrical center of the four reference stars as the origin. The values of X and Y are listed in Table III. We are now ready to substitute our values of X_1, Y_1, and δX_1 into equations (6) and (6′). We have:

$$+133.0\,a + 19.5\,b = +.042$$
$$-16.0\,a + 104.9\,b = +.100$$

Solving as simultaneous equations:

$$a = +.0002$$
$$b = +.0009$$

In the same way we solve for the plate constants *d* and *e*, thus:

$$+133.0\,e + 19.5\,d = -.013$$
$$-16.0\,a + 104.9\,d = +.039$$
$$d = +.0003$$
$$e = -.0001$$

Note that the essence of the Christie-Dyson method is to obtain a large coefficient for *a* and a small coefficient for *b* in one equation, and to reverse the situation in the other equation.

Since the plate constants are now known, they may be substituted in equations of the form

$$\delta X - aX - bY = r \quad \text{and} \quad \delta Y - eX - dY = r'$$

as has been done in Table III. The residuals (*r* and *r′*) should be small for the reference stars. If they are not small at least one reference star must have appreciable motion and it may be better to select additional reference stars and make a second determination.

Finally, the values of *r* and *r′* for the star *S* represent its proper motion in right ascension and declination. The motions expressed in seconds of arc per year are obtained by multiplication with a factor depending on the scale of the telescope and division by the time interval between the two plates, accordingly:

$$\mu''_\alpha = +0.335\,\frac{20.75}{39.00} = +0''.178 \text{ per year}$$

$$\mu''_\delta = -0.086\,\frac{20.75}{39.00} = -0''.046 \text{ per year}$$

Proper motions obtained thus are relative to those of the reference stars. For statistical purposes they should be "reduced to absolute" by correcting for the mean motions of the reference stars.

To facilitate the use of the Astrographic Catalogue one can refer profitably to the Hamburg tables,[3] which include a collection of different formulas for expressing standard coordinates as equatorial coordinates and *vice-versa*. This information is particularly valuable since the methods of presentation used in the Astrographic Catalogue are so heterogeneous.

The writer wishes to express her appreciation to Dr. A. N. Vyssotsky who suggested the subject of the paper and encouraged her to write up a detailed explanation of the method. She is also grateful to Dr. Bart J. Bok and Dr. Priscilla Fairfield Bok who read the paper very carefully and suggested a number of improvements.

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[1] W. H. M. Christie and F. W. Dyson, *M.N.R.A.S.*, Vol. 55, No. 2, 1894.
[2] W. M. Smart, "Spherical Astronomy," pages 307-309, 1931.
[3] "Hilfstafeln der Hamburger Sternwarte in Bergedorf," Part G, Table 101, 1924.

HARVARD COLLEGE OBSERVATORY, FEBRUARY, 1946.

The Development of Astronomical Photometry

By HAROLD F. WEAVER

(Continued from page 464)

The Selective Receivers. While the non-selective receivers of radiant energy have been useful in many astronomical applications, they have, because of their general lack of sensitivity, compared to the photographic plate for example, and their consequently specialized applications, never been used extensively. The selective receivers, on the other hand, because of their very great sensitivity are continually assuming a position of greater and greater importance in astronomical photometry. In many applications the photocell is now at the stage where it quite generally can displace, and in many instances is displacing in the field of photometry, the photographic process.

The various photocells which can be used in photometry can conveniently be classed as photo-voltaic cells, in which light produces directly or indirectly an electromotive force; photo-conductive cells, in which light produces a change in electrical conductance; and photoelectric cells, in which light causes the emission of electrons by the well-known photoelectric effect. Of all of these, the photo-voltaic cells have been known the longest having been discovered in 1839 by E. Bequerel[158] who observed that when one of two electrodes immersed in an electrolyte was illuminated, changes of potential occurred. Later, in

[158] *C. R.*, **9**, 561, 1839.

1877, Adams and Day[159] noted the appearance of an electric current in an illuminated selenium rod, and from this discovery has come the barrier layer photocells so familiar in the form of photographic exposure meters. Still later, at the beginning of the present century, it was discovered that certain crystals, notably galena, molybdenite, and cuprous oxide, produced an electric current upon irradiation.

The phenomenon of photo-conduction was first observed by Willoughby Smith[160] in 1873 when he found that tiny rods of selenium that he was using as high-resistance elements in an experimental circuit set up in a trans-atlantic cable station became much better conductors of electricity when exposed to daylight or any artificial illumination.

The photoelectric effect was discovered later still. It was first observed by Heinrich Hertz[161] during his classical experiments on the effect of electrical discharges in one oscillatory circuit upon another similar circuit not directly connected to the first. Hertz observed during the course of these experiments that the length of the secondary spark was consistently longer when light from the parent initiating spark fell on the secondary spark gap. Through numerous experiments he concluded that this effect appeared in proportion to the amount of ultraviolet radiation received from the primary source, and gave an elegant proof of this by placing before the secondary spark gap a slit and a large quartz prism. Upon passing the secondary gap through the spectrum of the parent arc formed by the prism, he demonstrated that the effect appeared only when the gap reached the region beyond the range of visible light and was located in the near ultraviolet.

A year later, Wilhelm Hallwachs, feeling that there must be a fundamental effect due to irradiation of materials by ultraviolet light which should be independent of spark gaps and electric discharges, extended Hertz's experiments and established the fact that a body carrying a charge of negative electricity readily lost that charge when irradiated with ultraviolet light. He also found that a positively charged body was not discharged under the influence of light. Other investigators began to work on this so-called "Hallwachs Effect." Elster and Geitel investigated the effect of light on some of the alkali metals. In 1899 they found that sodium and potassium were photoelectrically active to ordinary visible radiation, and with these experiments the development of the modern photoelectric cell began.

In 1895, G. M. Minchin,[162] after spending a number of years in experimental work on photocells and their properties, attached an electrolytic photocell of his own construction to a reflecting telescope of 24-inches aperture and obtained measurable electrical effects when the cell

[159] *Proc. Roy. Soc. London*, **25**, 113, 1877.
[160] *Soc. Tel. Eng.*, **2**, 31, 1873.
[161] *Wied. Ann.*, **31**, 383, 1887.
[162] *Proc. Roy. Soc. London*, **58**, 142, 1895; **59**, 231, 1896.

was irradiated with light from Jupiter and Saturn, or from one of the stars, Vega, Arcturus, Regulus, or Procyon. In the photocell used by Minchin the surface on which the incident light was received was formed by depositing a thin layer of selenium on a surface of clean aluminum. This sensitive layer was immersed in a glass cell filled with oenanthol, and the cell was placed at the focus of the telescope so that the light from a star could be focussed on, or, better, just in front of this surface, in order that the selenium was illuminated over a large portion of its area. A quadrant electrometer of special design was used for measuring the potential difference caused by the action of starlight on the light sensitive surface.

Other observers[163] made use of photocells in attempts to observe lunar and solar eclipses. It was not until 1907, however, that astronomical results of real interest and of importance were forthcoming. In that year Stebbins and Brown[164] made use of a selenium cell attached to the 12-inch refractor at the University of Illinois in an attempt to measure starlight. The cell, however, proved to be insufficiently sensitive to give a measurable change of electrical resistance even when exposed to the brightest object in the sky, Jupiter. Thus failing to obtain a response to all stars and planets, Stebbins removed the cell from the telescope and, holding it out in the open, demonstrated that it would respond to the light of the full moon, whereupon was started a study of the variation of the moon's light with phase.

The commercially available cells used in this study were formed of two wires closely wound in a double spiral around a flat insulator, the spaces on one face being filled with properly sensitized selenium.

In essence, the method of observing consisted in exposing the cell to the light to be measured (usually for ten seconds), and determining the change in resistance in the cell, this being accomplished by means of a Wheatstone bridge and a galvanometer. During this early photoelectric investigation of the moon's light several different cells were used in the observations, and it was soon discovered that different cells had widely different curves of color sensitivity. All cells, however, were relatively more sensitive to red light than to blue.

Later in 1907 further experiments on the photometry of stars with selenium cells were carried out, and finally small galvanometer deflections were observed[165] for Aldebaran. Improvements took place in the photocells continuously once they began to be used regularly, and it soon

[163] Stebbins, in a review of the early developments of photoelectric photometry (*Publ. A.S.P.*, **52**, 237, 1940), states that Pickering (with characteristic vision and awareness of new developments!) had tried to perfect a selenium photometer at some time before 1878—the effect of light on selenium was discovered in 1873—, and that G. E. Hale, very early in the history of photoelectric cell as developed by Elster and Geitel, had tried to detect the solar corona in full sunlight with a cell made by those experimenters.

[164] Stebbins, *Op. Cit.*, p. 236

[165] Stebbins, *Op. Cit.*

became possible to observe fainter stars. The results obtained, however, showed numerous irregularities. As experience accumulated, ways of eliminating these were discovered. It was found, for example, that the sensitivity of the cell was greatly improved, particularly from the point of view of constancy, if the cell were maintained at a low uniform temperature in an ice pack; that current should pass continuously through the selenium; and that exposures to light should be short with relatively longer periods allowed for the cell to recover.

In 1910, Stebbins[166] reported his observations of the eclipsing variable Algol made with a selenium photometer. He found that under good conditions a ten-second exposure of Algol to the cell gave a galvanometer deflection of approximately eight mm, the probable error of a deflection determination being about two per cent of its observed value, a result better than that generally secured in visual work.

The method of observing employed by Stebbins in his measurements of Algol made use of two stars of constant light, α Persei and δ Persei, which were used as comparison objects. Four galvanometer deflections were generally taken on α Persei, then eight on Algol, and then four on δ Persei. Such a set of observations required about 20 minutes to make, and yielded a value of the difference in magnitude between the variable and a comparison star with a probable error of approximately $0^m.02$.

Stebbins' observations showed the secondary minimum in the light curve clearly (the first time it had ever been observed) and probably formed the most accurate set of photometric observations in existence at that time. The probable error of a normal place on the light curve near primary minimum was $\pm 0^m.023$ (three sets of observations in a normal place), or near secondary minimum (six sets of observations in a normal place), or between minima (nine or more sets of observations in a normal place) $\pm 0^m.006$.

In 1911 Kunz suggested[167] that the photoelectric cell might with advantage replace the selenium cell. Sometime later, in 1913, Schulz and Kunz at the University of Illinois published[168] what are very probably the first stellar measurements made with this type of instrument. The cell used consisted of a simple spherical glass bulb some five cm in diameter approximately in the center of which was located the anode, a platinum wire bent into the form of a rectangle of dimensions $1 \times 1\frac{1}{2}$ cm. The terminal and support of this anode passed out of the tube through a glass sleeve to one side of the bulb. The bulb was evacuated and on its inner surface facing the plane of the rectangular anode was evaporated a layer of potassium which formed the cathode. Hydrogen was then

[166] *Ap. J.*, **32**, 185, 1910.
[167] Stebbins, *Pub. A.S.P.*, **52**, 237, 1940.
[168] J. Schulz, *Ap. J.*, **38**, 187, 1913. Details of the apparatus will be found in this paper.

introduced into the bulb and the potassium was, by electrical treatment, converted into a surface of potassium hydride of the type most sensitive to light. The bulb was again evacuated and filled with helium to an optimum pressure and sealed off.

The measurements of starlight were made by means of a quadrant electrometer, one pair of quadrants of which were connected to the photocell cathode. The photoelectric current produced in the cell was determined by the rate of deflection of the electrometer. This method worked well during the winter months when the cell was cold; when the weather became warmer, however, it became necessary to devise an additional compensating electric circuit to eliminate the so-called "dark current," the natural current leak through the cell which became large when the cell became warm.

At the same time that Kunz and Schulz were working on their apparatus at Illinois, very similar photoelectric photometers were being independently designed and installed by Guthnick[169] at Berlin and by Rosenberg[170] and Meyer at Tubingen. The conclusions drawn from these three independent investigations were in agreement: the photoelectric cell was a remarkably sensitive instrument, and was certain to replace the selenium cell in astronomical applications. The photoelectric cell clearly, even from the start, outclassed all other forms of photometers from the point of view of accuracy and sensitivity.

From the time of these early experiments even to the present moment, the history of the stellar photoelectric photometer has been one of constant improvement in both accuracy and sensitivity. Among the early improvements in the cells themselves may be mentioned the use, beginning in 1916, of quartz envelopes for the cells because of the better insulation[171] afforded by that material.

The greatest improvements in the techniques of photoelectric photometry, however, have occurred in the methods of measuring the current generated by the light of the star under study. Ives,[172] in 1914, stated that at that time five methods of measuring photoelectric current were to be found in the literature. The current could be measured: 1. by the rate of drift of an electrometer needle; 2. by the ballistic method, or the charge acquired in a definite exposure time by an electrometer connected to the cell; 3. by measuring the potential across the terminals of a high resistance in series with the cell; 4. by balancing the photoelectric current with a current variable in a known manner, using either an electrometer or sensitive galvanometer as a detector; 5. by the deflection of a sensitive galvanometer.

Of these various methods the deflection of a sensitive galvanometer

[169] *A. N.*, **196**, 356, 1913.
[170] *V. J. S.*, **48**, 210, 1913.
[171] Stebbins, *Op. Cit.*, p. 238, and *Ap. J.*, **74**, 295, 1931.
[172] *Ap. J.*, **39**, 431, 1914.

was the simplest and most convenient, but, unfortunately, because of the extremely small currents produced by the photocell, could be used only in conjunction with a source much brighter than a star. In the early work in photoelectric stellar photometry, therefore, some type of electrometer was customarily used in the measurements of the photoelectric currents. Schulz and Kunz[173] used a quadrant electrometer; Guthnick,[174] and Rosenberg[175] and Meyer as well as the later observers for some years thereafter used a simple string electrometer generally of the taut wire Wulf type.[176] In this latter type of instrument a fine gilded quartz fiber (or very fine platinum wire), for example, was stretched vertically, parallel to two equidistant knife edges one of which is charged negatively, the other positively. The suspended fiber was connected to the anode of the photoelectric cell, the cathode of the cell being connected to the negative terminal of a suitable battery or other source of direct current. The fiber was ordinarily grounded. If the ground connection was broken at any time and star light allowed to fall on the cell, a charge built up on the fiber which deflected towards one knife edge. The measure of the brightness of the star was obtained by measuring the time required for a certain charge to build up, that is, for the fiber to deflect by a certain specified distance, or by measuring the charge built up in a fixed time, that is, the deflection observed after the cell had been exposed to the star for a specified time.

Difficulties with such a string electrometer were encountered, however, since it had to be maintained in a vertical position, and it had also to be fixed close to the cell at the eye end of the telescope, and thus a special box and installation for the electrometer were necessary. The Lindemann electrometer,[177] was developed in 1924 for the specific purpose of eliminating these annoying necessities, and its almost immediate acceptance and use in astronomical photoelectric photometry marked a considerable advance in the field. This electrometer, essentially a combination of the quadrant and string electrometers, consisted of a needle which was suspended at its center of mass on a torsion fiber in such way that it could rotate between four cross-connected plates or quadrants. The fiber was fixed at both ends and was under tension so that the center of rotation of the needle remained fixed. The rotation of the needle which took place as a charge was built upon it as in the string electrometer could be observed through a microscope equipped with a suitable reticle. A mirror was thus unnecessary and the moment of inertia of the moving parts could be kept very small. It was found in practice that the sensitivity of this instrument was independent of position, and

[173] *Op. Cit.*
[174] *Op. Cit.*
[175] *Op. Cit.*
[176] Wulf, *Phys. Zeitsch.*, **15**, 250, 611, 1914; see also Strong, "Procedures in Experimental Physics," Prentice-Hall, Inc., 1943, p. 242.
[177] Lindemann, Lindemann, and Kerley, *Phil. Mag.*, **47**, 577, 1924.

that the zero point was almost independent of the instrument's orientation. The sensitivity of the Lindemann electrometer, while not so high as that of the most sensitive type of electrometer, could be made sufficiently great for general photometric purposes.

The electrometer, in spite of these improvements was, in general, however, never as satisfactory as might be desired. Mechanically, an electrometer of any type is at best a fragile and sensitive instrument and even under the most favorable circumstances not well adapted to semi-portable operation at the eye end of a telescope. These electrometers which were so used were of more rugged construction than was desirable from the point of view of attaining the highest electrical sensitivity, and the measurements made with them were less precise than was desired. Moreover, electrometers depended upon the atmosphere for their damping, and in spite of precautions taken to dry the air which surrounded the electrometer and other apparatus in the photometer case, the results obtained with such photometers operating at atmospheric pressure were often erratic and unpredictable.

The necessity for the use of electrometers in general photoelectric photometry was eliminated in 1932 by Whitford[178] who in that year perfected a thermionic amplifier employing an FP-54 Pilotron tube which could be applied to a photoelectric photometer. With this apparatus the current generated in the photoelectric cell by the light of a star was amplified by a factor of approximately 2,200,000, and could be measured directly by the deflection of a sensitive galvanometer. This new type of equipment, in addition to being a great deal more convenient to use than the older electrometer, was also more sensitive than that device. Moreover, since there was no longer any need for having air in the immediate vicinity of the photometer for damping purposes, all the apparatus carried at the eye end of the telescope could be placed in an evacuated case. By so evacuating the region around the photometer, the instrument was stabilized, and troubles arising from poor or defective insulation and moist air were eliminated to a marked degree. The galvanometer used for measuring the currents did not necessarily have to be in the immediate vicinity of the photoelectric cell as did the electrometer, if the best results were to be achieved. It could be located at some distance from the telescope in a stable position where it could be used at its maximum efficiency.

But unfortunately the amplifier and galvanometer, by far the most convenient instruments to use in conjunction with a photoelectric cell in the measurement of the brighter stars, and to the introduction and perfection of which may be traced by far the majority of advances made in the field of photoelectric photometry in recent years, are not the most efficient means of measuring faint stars near the limit of sensitivity

[178] *Ap. J.*, **76**, 213, 1932.

of the equipment.

The size of the random error of a single photoelectric measurement of the brightness of a star can be measured (at least in one way) by the ratio of the average difference between successive galvanometer deflections to the average galvanometer deflection for that star. Since in a photoelectric photometer we are dealing with electrical phenomena, we may liken these random variations in the galvanometer deflections to random currents which in an audio instrument would cause noise. The average galvanometer deflection we may term the signal. Clearly, then, the quantity which determines the accuracy of the observations made with a photoelectric photometer is the ratio of signal to noise. The stronger the signal compared to the background noise, the more accurate the observation. One of the most readily understandable sources of noise in a photoelectric photometer is the "seeing" which has been shown by Whitford and Stebbins to cause not only a variation in the form and shape of the telescopic image, but a variation in the intensity of the image as well.[179] Other sources of noise reside in the apparatus itself; in the statistical fluctuations in the rate of release of electrons by the photoelectric cell even when irradiated with light of constant intensity; the dark current of the cell, and the residual grid current of the amplifying tube. Thermal noise can arise from a grid resistor if one is used, or from sources within the cell such as irregular current leakage through a thin conducting film. Other sources of amplifier noise which may be large under some conditions are found in imperfect equipment such as unsteady batteries, ineffective shielding, and imperfect contacts. These last sources, of course, can be reduced to values so small that they are of no importance.

This noise arising from the apparatus itself maintains an approximately constant value; the "seeing" noise, on the other hand, has a value which is, on the average, equal to approximately one per cent of the signal. When the signal is of such strength (that is, when the star is sufficiently bright) that the "seeing" noise has a far greater value than the noise of the apparatus, it is the major factor in determining the uncertainty of the measurement. When the absolute value of the "seeing" noise (which decreases as the signal decreases) finally attains a value equal to or less than the level of the amplifier and cell noise, this latter disturbance becomes the dominant factor in determining the size of the random error of an observation. The point at which the amplifier and cell noise take on this dominating position may be termed the "seeing" accuracy limit. Corresponding to this "seeing"accuracy limit is a signal of a certain intensity or, put otherwise, a signal caused by a star of a certain magnitude which may be specified. For stars brighter than this limiting magnitude, the size of the random error will be essentially

[179] G. E. Kron, *Pub. A.S.P.*, **52**, 25, 1940; Stebbins, *Sky and Telescope*, **3**, No. 4, p. 7, 1944.

constant and will be determined primarily by the quality of the night on which the observations are made, that is, primarily by the quality of the "seeing." For those stars fainter than the magnitude corresponding to the "seeing" accuracy limit, the size of the random error is controlled primarily by the ratio of the level of the amplifier and cell noise to the strength of the signal. The amplifier and cell noise level remains essentially constant; the strength of signal decreases as the brightness of the stars measured decreases. The percentage random error of a measurement, determined by the signal-to-noise ratio, therefore rapidly increases as the signal strength decreases below the level of the seeing accuracy limit.

With the electrometer, on the other hand, no amplifier is used, and hence no extraneous noise is introduced. In using such an instrument, we make a measurement by noting the rate of deflection of the needle or mirror involved. Thus, essentially we count the number of electrons which are liberated from the cell and charge up the electrometer in a given period of time, and from this get the rate of deflection or number of electrons arriving at the electrometer, say, per second.

Neglecting the dark current from the cell and small leaks in the leads, or tendencies of those same leads to pick up stray ions, the main source of uncertainty in electrometer measurements is found in the "seeing" noise and in the random fluctuations in emissivity of the cell which occur even if a perfectly constant light source is used to irradiate it. These fluctuations it has been shown,[180] obey the usual laws of probability. We can therefore make the error in the determination of the rate of deflection small by counting a sufficiently large number of electrons, that is, by allowing the electrometer to charge up for a sufficiently long time. We must take care in such measurements, however, that the measuring instrument itself does not fail. Fortunately, with an electrometer of the Hoffmann type numerous experiments have shown that it is possible to extend measurements over a considerable period of time without fear of difficulties. When used as a charge-measuring instrument the Hoffmann electrometer is a device of great sensitivity. It is also a device of great stability, and electrons can be collected with it over any desired observing interval.

Thus the magnitude of faint stars can be measured most satisfactorily with a photocell by connecting the cell directly to a Hoffmann electrometer and making no use of an amplifier.

In order to improve the performance of a photoelectric photometer and amplifier as applied to the faint stars to the point where it can compete with an electrometer for accuracy, it is necessary to improve the signal-to-noise ratio. It does not seem likely that this can be readily accomplished by decreasing the amplifier noise since that quantity is,

[180] E. Steinke, *Zeitschr. f. Physik.*, **38**, 378, 1926.

in most instances, already near its theoretical minimum. The greatest hope for improvement seems, therefore, to lie in the direction of improving the photoelectric cell itself.

Recent developments made by Kron[181] at the Lick Observatory make it appear probable that through use of the principle of the electron multiplier[182] it will be possible to push the seeing accuracy limit several magnitudes beyond the present position of that limit towards the faint end of the scale without the use of an electrometer. "By means of the multiplier principle very large amplification of the photo-current can be accomplished previous to the introduction into the circuit of a measuring device. Thus, if a noise-free amplification factor of, say, 1,000 can be obtained before a vacuum tube and its grid resistor need be employed, then the ratio of signal to externally-introduced noise will generally be increased by a thousandfold, and the primary random noise of the photo-current may then be predominant. It is clear that, from a theoretical point of view, the photo-multiplier should make possible the achievement of a high signal to noise ratio without the use of delicate and impractical equipment."[183]

Employing a very simple photoelectric photometer having as its essential parts an RCA 1P21 multiplier (which was designed expressly for measuring faint light sources) with a battery voltage supply, a small D.C. amplifier, and an indicating meter, Kron has demonstrated that there is now available a new type of photoelectric photometer some 10 to 25 times more sensitive than anything previously available.[184]

It is of interest at this point to determine to what magnitude limit this sensitivity increase will allow us to work, and at the same time to trace the course of the steadily increasing sensitivity of photoelectric photometers since their first astronomical applications.

In Table VI will be found data describing the sensitivity and accuracy

[181] *Ap. J.*, in press. It is a pleasure to thank Dr. Kron for the opportunity to read this paper in advance of publication.

[182] V. K. Zworykin, G. A. Morton, and L. M. Malter, *Proc. I. R. E.*, **24**, 351, 1936. The principle of the electron multiplier tube is very simple. In such a tube there are several sensitive surfaces. Light strikes the first photo-sensitive surface and electrons are released. These are focussed electrically so that they impinge on a second sensitive surface especially sensitized for secondary emission. Here more electrons are liberated. These in turn strike another surface, the number of electrons liberated is again increased, and so forth. At each of these surfaces the number of electrons is multiplied. By employing several stages it is possible to have the final output of electrons several thousand or even million times the number originally liberated by the beam of light.

[183] Kron, *Op. Cit.*

[184] The 1P21 multiplier may also be operated by using a galvanometer connected directly in series with its anode circuit. While the use of a galvanometer in this fashion does not take full advantage of the multiplier owing to the insensitivity of the galvanometer the arrangement is simple and does have a number of applications. With such an arrangement used in conjunction with the 36-inch Lick refractor stars of magnitude 11 can be measured.

TABLE VI

THE SENSITIVITY AND ACCURACY OF VARIOUS REPRESENTATIVE PHOTOMETERS

Year	Type of cell and measuring apparatus	Limit of Detection	Workable limit and prob. error of meas.	Size of Telescope	—Reduced to 100″— Limit of Detection	Workable limit and prob. error of meas.	Source of Information and Remarks
		m	m m		m	m m	
1914	Selenium and galvo.	...	3 ± 0.01(?)	12″	...	7.6 ± 0.01(?)	Stebbins, *Ap. J.*, **39**, 459, 1914.
1915	Photo-el. and electr.	5	3.5 ± 0.005	12″	9.6	8.1 ± 0.005	Kunz and Stebbins, *Pop. Astr.*, **23**, 603, 1915.
1929	Photo-el. and electr.	...	7 ± (?)	15″	...	11.1 ± (?)	Stebbins, *Pop. Astr.*, **37**, 388, 1929. Lindemann electrometer.
1932	Photo-el. and galvo.	14.3	9.0 ± 0.03	15″	(18.4)	13.1 ± 0.03	Whitford, *Ap. J.*, **76**, 213, 1932. First electronic amplifier. Detection limit too optimistic?
1933	Photo-el. and electr.	~17	14 ± 0.03(?)	60″	~18.1	15.1 ± 0.03(?)	Smith, *Phys. Rev.*, (2) **43**, 211, 1933. Hoffman electrometer.
1940(?)	Photo-el. and galvo.	18.5	16.1 ± 0.04	100″	18.5	16.1 ± 0.04	Stebbins, *Pub. A. S. P.*, **52**, 235, 1940. Electronic amplifier. Rate of charge method; photographic registration.
1940	Photo-el. and galvo.	...	8.0 ± 0.003 10.3 ± 0.030	36″	...	10.2 ± 0.003 12.5 ± 0.030	Kron, *Pub. A. S. P.*, **52**, 250, 1940. Electronic amplifier.
1946	Photo-el. multiplier and galvo.	...	13 ± 0.003 16 ± 0.03	36″	...	15.2 ± 0.003 18.2 ± 0.03	Kron, *Ap. J.*, in press. Electronic amplifier.

of various representative photometers. In the first few columns of this table will be found the numerical data as quoted in the original papers cited, in columns six and seven are the results of an attempt to reduce these data to a homogeneous system referred to the 100-inch reflector. Unfortunately, because of the several types and sizes of telescopes used by the various observers no great accuracy can be claimed for these reduced data. In obtaining them no allowance has been made for the absorption of light in lenses or the reflectivity losses of mirrors. Likewise, no attempt has been made to allow for the decreased effect of seeing (for a star of given magnitude) with increase in telescope size. The quoted values should, on the whole, probably be considered as conservative estimates of the magnitudes that can be reached with the stated errors.

From an inspection of the values in this table it is immediately evident that with the introduction of the multiplier tube a great new advance in photoelectric photometry has been made. As to future developments of this device, Kron[185] states in regard to what he calls an ideal multiplier operating under ideal conditions: "Our multiplier will be constructed with a quartz envelope for best insulation of the anode, and it will have a cathode area only ⅕ that of the 1P21 in order to reduce the dark current by a factor of five; there will still be sufficient area to receive all of the light from a star or faint nebula. The multiplier will have only three or four stages for the sake of simplicity of construction, but it will operate at a multiplication factor of 12 per stage, to reduce the effects of emission from the secondary surfaces. Such a multiplier, when operated at the temperature of dry ice, will have a dark emission from the photo-surface of about one electron per second; the sensitivity, on the other hand, will be about 4.4×10^5 electrons per second from light of the standard source [used in the original tests and] collected with a reflecting telescope. The quartz envelope of the multiplier will transmit radiation from the deep blue and near ultraviolet region of the spectrum, so that the sensitivity will be increased by a factor of approximately 2 when a reflector is used [rather than a refractor]. A simple calculation shows that a star of 21.4 magnitude at the focus of the 100-inch telescope would give a current of 20 electrons per second from the primary surface of our ideal multiplier. We will now make our observations by counting electrons with one of the new commercially-available pulse counters, and will operate the counter so that it will not respond to pulses unless they are of such amplitude that they originate from the photo-surface. The lesser amplified dark electrons emitted from the secondary surfaces will thus not be counted at all, and they need not be considered further. Inasmuch as the electrons are emitted in a random fashion, we will have to count 1000 of them to make an observation having an accuracy of $\pm$ 3 per cent, and this

[185] *Op. Cit.*

will require 50 seconds. The dark-current emission, if constant, need be checked only at rare intervals, so that in practice we may neglect the time required for its determination."

Specialized fields of application of the photocell. The possible applications of the photocell in the field of astronomy are, to quote Stebbins, "limited only by the imagination of the user." At one time or another the photocell has been applied to all those fields of photometry which have so far been mentioned. Its most frequent applications, however, have been in the fields of variable star photometry (particularly eclipsing binary stars), color photometry, spectrophotometry, and surface photometry (nebulae, clusters to some extent, and, in recent years in particular, the night sky).

In the field of variable star photometry Stebbins'[186] early work on Algol with a selenium photometer has already been mentioned as the most accurate[187] work of its kind then in existence. The study of light variations of eclipsing stars was also one of the first applications of photoelectric photometers.[188] Among the numerous light curves which have been determined photoelectrically since 1914, the most outstanding ones so far published are without doubt those established in red and blue light[189] for YZ Cassiopeiae by Kron[190] at the Lick Observatory. The probable error of a normal point on the light curve of this system is, in the blue, $\pm 0^m.0011$, and, in the red, $\pm 0^m.0009$. From curves of such high accuracy as this (a far cry indeed from the best work possible only a few decades ago!) accurate values of the limb darkening of the components of the binary system can be derived as Kron has demonstrated.

Color photometry has likewise been one of the important fields of application of the photoelectric cell since its introduction into astronomical photometry. In 1916 Guthnick and Prager[191] measured color indices for a number of stars by determining their differences in brightness when observed with and without a yellow filter in front of the cell. The first extensive list of star colors thus determined was published by Guthnick and Hügler[192] in 1920. While the numerical accuracy of the colors determined by Guthnick and Hügler was rather high, the percentage accuracy was not so high as might be desired in-

[186] *Ap. J.*, **32**, 185, 1910.

[187] Probable error of a normal point in most favorable region of curve: $\pm 0^m006$.

[188] P. Guthnick and R. Prager, *Veroff. der K. Sternw. zu Berlin-Babelsberg*, **1**, Heft 1, 1914, included among their observations of various eclipsing binaries numerous measurements of the light of Mars and Saturn.

[189] Two cells of different spectral sensitivity ranges were used in the determination of these curves. For the blue curve (effective wave length 4500 A) Kron used a Kunz potassium-hydride cell; for the red curve (effective wave length 6700 A) a cesium-oxide-on-silver cell.

[190] *L. O. B.*, **19**, 59, 1939; *Ap. J.*, **99**, 173, 1942.

[191] *Veroff. der Universitatssternw. zu Berlin-Babelsberg*, **2**, Heft 3, 1918.

[192] *A. N.*, **210**, 345, 1920.

asmuch as the base line of their color system was rather short, being only about one-quarter that of King's photographic system. This inconveniently short base line was extended by the simple expedient of using two filters in the measurements,[193] a yellow one and a blue one, and thus approximately doubling the color range. Some observers preferred to make use of two cells of different color sensitivities for the determination of star colors. Quite generally, however, the one-cell two-filter method has proved to be the simplest and most popular method.[194]

Recently, Öhman[195] has proposed a more elaborate method of flicker photometry for the photoelectric determination of stellar colors. The recording part of Öhman's apparatus consisted of a vacuum-tube alternating-current voltmeter which recorded at a frequency of 137 per second. A rotating polarizer, of which the axis of the rotation coincided with the optical axis of the telescope, was placed in the path of the light rays. Between the rotating polarizer and a polarization filter used as an analyzer, two quartz plates were interposed. One of these plates was cut parallel to the optical axis of the crystal, the other perpendicular to the axis in order to give rotary dispersion. As the polarizer rotated at a rapid rate, two complimentary colors alternately struck the photoelectric cell. The flicker effect—the response of the cell to the effectively unequal intensities of light striking it in rapid succession—disappeared when the two colors were adjusted to produce equal currents in the cell. By rotating the second quartz plate, the colors, and hence the amplitude of the flicker current could be changed. That position of the plate at which the flicker was eliminated served as a measure of the color of the star.

The extension of photoelectric color photometry to photoelectric spectrophotometry was a natural forward step that followed the perfection of suitable photoelectric cells sensitive to radiation over a wide spectral range. One type of cell having such a wide spectral response had for its cathode surface a layer of cesium oxide on silver, and was sensitive to light within the wave-length range 2000 A to 12,500 A. Unfortunately, however, it exhibited under ordinary circumstances a dark current so large as to make it unusable in astronomical applications. In 1931 Hall[196] demonstrated that this current could be reduced to a relatively small quantity by cooling the cell with dry ice, and with a photom-

[193] K. F. Bottlinger, *Veroff. der Universitatssternw. zu Berlin-Babelsberg*, **3**, Heft 4, 1923.

[194] Among the more extensive catalogs of photoelectric star colors determined by the one-cell two-filter method may be listed those of Bottlinger, *Veroff. der Universitatssternw. zu Berlin-Babelsberg*, **3**, Heft 4, 1923; of Elvey, *Ap. J.*, **74**, 298, 1931, (effective wave lengths 3850 A and 5100 A); of Becker, *Veroff. der Universitatssternw. zu Berlin-Babelsberg*, **10**, Heft 3, 1933; and of Stebbins, Huffer, and Whitford, *Pub. of the Washburn Obs.*, **15**, pt. 5, 1934; *Ap. J.*, **91**, 20, 1940, (effective wave lengths 4260 A and 4770 A).

[195] *Stockholm Medd.*, No. 54; *C. D. A. L.*, Bulletin 13, p. 3.

[196] *Ap. J.*, **79**, 145, 1934.

eter equipped with such a refrigerated cesium-oxide cell[197] made color observations in the red spectral regions of a number of stars.

In 1935 Hall[198] began making spectrophotometric measurements with a photoelectric photometer employing a cesium-oxide cell. Spectra were produced by means of a normal wire objective grating giving a dispersion of 438 A/mm in the focal plane of the telescope used. An ingenious mechanical-optical device made it possible to superimpose on the light sensitive surface of the photocell both first order spectra at any specified wave length, and hence to measure the sum of their intensities. Measurements were made at 12 points between the limits λ 4550 and λ 9830 in the spectrum of each object studied; each measurement covered a spectral range of 483 A. The probable error of an observation (two readings) made with this apparatus varied somewhat with the region of the spectrum under observation owing to the variation of sensitivity of the cell with wave length and other factors, but was, on the average, approximately $\pm 0^m.03$.

Stebbins and Whitford[199] have used a refrigerated cesium-oxide cell photometer in conjunction with a series of six color filters for the spectrophotometry of stars and nebulae by a method similar to that used earlier by Nordmann in his visual spectrophotometric work and by Coblentz and Lampland in their work with thermocouples. The effective wave lengths of the regions measured with the filters were, according to Stebbins and Whitford, 3530 A, 4220 A, 4880 A, 5700 A, 7190 A, and 10,300 A.[200] The probable error of a measurement[201] made with the first and last filters in the series was $\pm 0^m.016$ and $\pm 0^m.017$, respectively, that made with one of the other four filters was less than $\pm 0^m.01$. A considerable number of objects has been surveyed by this method of six-

[197] While such a cell has highly desirable characteristics from the point of view of wave-length range, it does not (as Stebbins has shown in *Ap. J.*, **98**, 20, 1943) have the sensitivity or low dark current of a Kunz potassium-hydride cell. In particular, a cesium-oxide cell was found to have an overall sensitivity of 3.4×10^{-12} ampere for an A0 fourth magnitude star observed with the 60-inch telescope, and a dark current (with dry ice refrigeration) of 4×10^{-15} ampere. A Kunz cell under similar conditions (but not refrigerated!) had a sensitivity of 23×10^{-12} ampere for an A0 fourth magnitude star at the 60-inch telescope, and a dark current of 10^{-16} ampere or less. The cesium-oxide cell is somewhat at a disadvantage with its color sensitivity when compared to potassium-hydride cell for an A0 star. The comparison in regard to sensitivity is slightly better for the cesium-oxide cell on a G0 or later type star. As to spectral sensitivity, the Kunz cell responds to radiation within the wave-length range approximately 3500 A to 5000 A, or, in the extreme, possibly 3200 A to 5800 A; the cesium-oxide cell, on the other hand, responds to radiation within the wave-length range 2000 A to 12,500 A, as has already been mentioned.

[198] *Ap. J.*, **84**, 372, 1936; **85**, 145, 1937. Infrared magnitudes (effective wave length 8300 A) and colors (effective wave lengths 6800 A and 8300 A) were also determined.

[199] *Ap. J.*, **98**, 20, 1943.

[200] These values were obtained by combining the transmissions of the filters and the response of the cell obtained with an equal energy source.

[201] The values of the probable errors given here refer to a star brighter than magnitude 7.5. For fainter stars the values are larger than those quoted.

color photometry with highly satisfactory results.[202]

A further application of the photocell in the field of spectrophotometry which will undoubtedly prove to be of great importance in the near future is its use in the determination of line profiles through observations made directly in the focal plane of a spectrograph. Dunham,[203] at the Mount Wilson Observatory, has tested several such photoelectric microphotometers for use on the solar spectrum. In the first experiments, essentially a simple scanning device with a narrow slit (0.03 A wide) was moved in the focal plane of the spectrograph across the spectral line under examination. Unsteadiness in the atmospheric transmission, however, made it desirable to use a null method in which the intensity of the background, when reduced in a known ratio, was compared with that within the absorption line. Two methods of accomplishing this were tried. In the first method a D.C. amplifier with two cells working against each other was used. In the second, an A.C. flicker amplifier was used to compare the two intensities. The apparatus was arranged so that light within the line could be balanced either against light rejected by a monochromator just in front of the slit of the main spectrograph, or against light from the neighboring spectrum in the main spectrograph when no monochromator was used. Unfortunately, the complete development and testing of these instruments was interrupted by the war.

H. A. Brück,[204] at Cambridge, England, has also made tests of a recording photoelectric photometer for the solar spectrum of the same general type as those investigated by Dunham. In Brück's instrument there was, in addition to a narrow movable slit located in the focal plane of the spectrograph, a stationary slit also located in the focal plane of the spectrograph and in the immediate vicinity of the spectral region being examined. By having the intensity of the light entering this fixed slit recorded continuously or from time to time as the movable slit traversed the lines under study, momentary or gradual changes in the atmospheric transparency could be determined, and the line profiles obtained with the movable slit could be corrected for any errors arising from such changes.

The instruments tested by Dunham and Brück showed great promise; the perfection of such a recording solar photoelectric photometer operating directly in the focal plane of a spectrograph is an important instrumental problem for future solution.[205]

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[202] See *Ap. J.*, **98**, 20, 1943; **101**, 47, 1945; **102**, 318, 1945.

[203] *Phys. Rev.*, (2) **44**, 329, 1933; *Trans. I. A. U.*, **6**, 296, 1938.

[204] *M. N.*, **99**, 607, 1939.

[205] Instruments of the same general type as those described here have also been used in the laboratory. For a description of a recording photoelectric photometer employing an electron multiplier tube and operating in the focal plane of a large laboratory spectrograph, see, for example, C. H. Dieke and H. M. Crosswhite, *J. O. S. A.*, **35**, 471, 1945.

Among the more interesting applications of the photocell to the problems of the determination of surface brightness (aside from those of spectrophotometry just discussed) may be mentioned the study of the light of the night sky carried on by C. T. Elvey and F. E. Roach,[206] and the photometry of the Andromeda Nebula by Stebbins and Whitford.[207]

The photoelectric photometer used by Elvey and Roach in their study of the night sky was of the photographic recording type, and was so constructed and mounted that a series of tracings showing the variation and brightness over the entire sky could be made in about one hour. The photometer itself consisted of a Kunz potassium-hydride blue-sensitive[208] photocell used in conjunction with a Pilotron FP-54 tube and a balanced circuit type amplifier connected to a high-sensitivity galvanometer. From observations made with this apparatus it was possible to determine approximate intensity ratios of the various sources of radiation in the night sky; direct starlight, scattered starlight, light from the permanent aurora and the polar aurora, zodiacal light, light from galactic sources, light scattered by the atmosphere from all of these sources, and, finally, light scattered from terrestial sources.

Stebbins and Whitford, in their photometry of the Andromeda Nebula, have determined, among other things, the extent of the nebula and the variation in brightness and color along the axes of its nucleus.

The measurements of the extent of the nebula were made with a Kunz potassium-hydride photocell and an early amplifier constructed by Whitford. The observations did not extend completely around the nebula, but were made at various points along hour circles through the nebula; most readings were made along the hour circle through the nucleus. These measurements indicated that the nebula had apparent dimensions[209] of approximately 350′ by 90′ along an isophote at which the amount of light received from one square second of arc of the nebula is equivalent to that received from a star of magnitude 26 (26 mag. per square second of arc), and about 450′ by 110′ along the isophote 27 mag. per square second of arc. This larger size is considered doubtful because of the incompleteness of the observations at these

[206] *Ap. J.*, **85**, 213, 1937.

[207] *Proc. N. A. Sci.*, **20**, 93, 1934; *Sky and Telescope*, **3**, February, 1944, p. 8.

[208] Observations of the light of the night sky have also been made in the red region of the spectrum with a cesium-oxide photocell. See, for example, Elvey, *Ap. J.*, **97**, 65, 1943. It is interesting to note that Stebbins and Whitford (*Ap. J.*, **101**, 39, 1945), in the course of their six-color photometry, discovered an intense night-sky radiation at wave length 10,440 A. Swings (*Ap. J.*, **101**, 39, 1945) identifies this with a band arising from N_2.

[209] It was assumed in deriving these figures that the ratio of the axes of the nebula for these faint regions remains 4 to 1 as it is for the brighter portions.

greater distances from the nucleus.[210]

In their study of the nucleus of the Andromeda Nebula Stebbins and Whitford used the same photometer they employed in their six-color photometry and demonstrated that the brightness and color of the nucleus differed from one side to the other when measured along the minor axis. This they attributed to the fact that, because of the shape of the nucleus and the inclination of the plane of the nebula to the line of sight, the light from one side of the nucleus (along the minor axis) came in large part from stars located between the observer and the layer of obscuring material presumed to extend through the center of the plane of the nebula. Light from the apparently diametrically opposite part of the nebula came from stars lying behind this absorbing layer, and which therefore appeared relatively faint and reddened. From the differences in brightness and color between the two sides Stebbins and Whitford derived a value of the important constant χ, the ratio of total photographic absorption to color excess.

On the whole, the advantages and possibilities of the photoelectric photometer in the field of surface photometry have been very little exploited. Many interesting and important problems in the photometry of galactic and extragalactic nebulae, star clusters, and our own galaxy itself, to mention only a few problems, remain for the future work.

Photometry in the Future

Looking over the history of photometry as a whole, one cannot fail to be impressed with the relatively rapid changes in technique which have taken place at certain periods—the change from the purely visual and memory scale methods of Period I to the visual photometric instruments of Period II starting roughly in 1836, and the change from the visual methods of Period II to the photographic methods of Period III starting at about the turn of the present century. We are now once more in such a period of change. The developments which have taken place during the past few years in the construction of photocells[211] and the equipment that goes with them put the photoelectric methods of Period IV in a favorable position to displace, at least in part, the photographic methods and procedures of Period III. While it does not seem likely at the present time that photoelectric methods of photometry can or will displace photographic methods completely (at least in the near future) because of the economy of photographic methods from the point of view of telescope time, it is entirely possible that before many years photoelectric methods may very well replace photographic meth-

[210] Williams and Hiltner (*Pub. of the Obs. Univ. of Mich.*, 7, 103, 1941) have used their direct-intensity microphotometer in a slightly altered form to trace isophotes on a long-exposure photograph of the Andromeda Nebula taken with the 18-inch Schmidt camera at Mt. Palomar. They find that the apparent diameter along the major axis of the nebula is at least 400′.

[211] In particular the improvements in electron multiplier tubes.

ods of establishing magnitude scales. In a large statistical problem, in which many hundreds of magnitudes are required, for example, a photocell could be used to establish one or more magnitude sequences in the area under study. The magnitudes of all the other stars in the area could then be determined from photographs of the area, the photoelectrically established sequence serving to standardize the plates. Such a procedure would probably be at least as accurate as, and probably, in most cases, more accurate than the present purely photographic methods.[212]

And, as the photocell comes into more general use as it certainly will in the near future, it will find application in many new photometric problems. The applications of the photocell up to the present time have, on the whole, been rather limited to the study of eclipsing binaries and to the determination of star colors, with spectrophotometry and problems in surface photometry receiving some attention. It is likely that because of its astrophysical importance the field of spectrophotometry will receive more attention in the not distant future than it has in the past. Also, it seems likely that as photoelectric photometers come into more general use other fields such as the photometry of variable stars other than eclipsing binaries (cepheids, long-period variables, novae, and so forth), of extended surfaces such as nebulae (extragalactic and galactic), star clusters, and comets, as well as the other members of our solar system, will receive a much larger share of the attention of those working in photoelectric photometry than they have received up to the present time. An immense amount of work remains to be done in all of these fields; no doubt electron multiplier tubes will play an important part in all of them. This will be particularly true if a red-sensitive multiplier as satisfactory as the present blue-sensitive multiplier can be

[212] An example of a particular photometric problem of the general type in mind here (but involving no photography) and which is of considerable interest and capable of being solved with a photoelectric photometer and a small telescope is the accurate determination of the magnitudes (in the photographic and red regions of the spectrum) of all the stars brighter, say, than magnitude 6.5. While these bright stars do have visually determined magnitudes (some of them of high accuracy), it is a surprising fact that very many of them lack photographic magnitudes. The photographic determination of these magnitudes would be a very extensive undertaking. For the best results rather special wide-angle cameras (a Schmidt camera, for example) would be required; a very detailed discussion of possible sources of error would be necessary in order to make certain that the final system was accurate and homogeneous. The nature of the photoelectric photometer, however, simplifies these discussions, and this instrument offers the most rapid and most feasible means of determining the desired magnitudes, which, because of their use as a basis for discussions of the statistical aspects of the stars in the vicinity of the sun, are of particular importance. The careful specification of the color system used in such a program of photoelectric magnitudes, and the provision of means of transferring them from the given system to another photometric system are important problems. See the following footnote.

produced.[213]

In photographic photometry there still remain many problems of a fundamental nature. It seems likely that in spite of the probable general increase in the importance of photoelectric methods these photographic problems should nevertheless be undertaken.

The various difficulties which have been encountered in using the polar sequence have already been discussed—the inconvenient position of the pole, particularly for large instruments, the fact that the magnitudes and scale of the fainter stars have been determined at only one observatory and by methods which can now be improved, and so forth. Difficulties with the brighter stars of the sequence ($m \leq$ approx. 11.5) have, to a large extent, been eliminated by the publication of the excellent catalogue of "Magnitudes and Colors of Stars North of +80°" by Seares, Ross, and Joyner. For most smaller instruments of relatively short focal length for which small seeing differences between the field and the polar regions are not likely to cause appreciable systematic errors, these magnitudes will probably serve very well. Theoretically, however, it would be preferable to have available standard magnitude sequences of bright stars (even for small instruments) which are close to the area in which magnitudes are required. The meeting of this requirement necessitates, of course, the establishment of a whole series of standard sequences[214] scattered over the sky in the fashion of the Harvard Standard Areas or the Selected Areas. Such sequences, if they were to be established, should be set up with an accuracy at least comparable to that of the stars in the Seares, Ross, and Joyner catalogue. Sequences of the type and accuracy described would also possess the advantage that, if established in the region of the equator and south of the equator, they could be used and extended by observers in the southern hemisphere and thus both hemispheres could be connected by a consistent and homogeneous magnitude network.

The faint stars of the polar sequence are much more in need of checking and extension to other areas than the bright ones. For large instruments the pole is very inconveniently located from the point of view of obtaining comparable guiding for the polar exposure and that of the area under study; it is also lower in the sky than need be for most areas, and is, in general, farther away from the area under study than is de-

[213] With this very probably great importance of photelectric methods in the near future, the question of the color or effective wave-length systems of the various photocells becomes a matter of interest. In the future, each observer will have to give a sufficient number of data to enable other investigators to convert his photoelectric magnitudes to a standard system, another observer's system, or possibly the present standard photographic system.

[214] If such sequences should ever be established, particular attention should be paid to the inclusion in each magnitude interval of the sequences stars covering a wide range in color. There should be, if it is at all possible to arrange it, no correlation between average color and magnitude as there is in the present polar sequence.

sirable. Seeing, and possibly even transparency, differences are likely to cause systematic errors when the areas being compared are too far separated.

A program to check, and to extend to magnitude 20.5, the photographic scale[215] in a series of Selected Areas in the declination zones $+30°$ and $+15°$ by means of a platinum half-filter has been started by Baade at the Mt. Wilson Observatory, and is now nearly complete. The zero points of these scales, to be carefully intercompared, will be established by direct comparison with the polar sequence.[216] These scales, which will be of the highest accuracy, will go far towards replacing the faint part of the scale of the polar sequence. It is to be hoped that they will soon be generally available.[217]

There have frequently been discussions about the establishment and use of monochromatic or nearly monochromatic magnitude systems. Such a system would give magnitudes corresponding to an effective wave length that did not vary with the brightnesses and colors of the stars under study. Magnitudes of this type could undoubtedly now be established, at least for the brighter stars, by spectrophotometry or by means of filters, and experiments having as their goal the discovery of the most suitable methods of establishing such magnitudes should be started. Hertzsprung,[218] in discussing monochromatic magnitudes, has suggested that, inasmuch as the present photovisual magnitudes of the North Polar Sequence stars show practically the same effective wave length for stars of all colors, the effective wave length of that system, which may be taken as approximately 5500 A, be adopted as the effective wave length of one of the "monochromatic" magnitude systems he proposes to establish. He has further suggested that the present photographic system be replaced by one established by spectrophotometry of the spectral region between $H\delta$ and $H\epsilon$, and having a corresponding effective wave length of 4030 A. The color indices of $m_{4030} - m_{5500}$ would have, according to Hertzsprung, approximately twice the base line of the present color indices.

The merits of essentially monochromatic magnitudes are very great, but many of the stars that are now being studied photometrically (and that will be studied in the future) are very faint, and are at, or are very near to, the lower limit of brightness that can be photographed even when the relatively broad wave-length region now generally employed is used. It does not seem likely, therefore, that a photometric system applicable only to the relatively brighter stars will displace to any large

[215] On the international color system.

[216] It will be necessary to specify, of course, the magnitude range in the polar sequence which has been used for these comparisons, and to keep this same range for all comparisons made.

[217] It will be of interest to determine, at some future date, the colors of the stars in these sequences.

[218] *Trans. I. A. U.*, **6**, 407, 1938.

extent, at least in the near future, the current system. For many specialized purposes, particularly in statistical discussions where the very faintest star are not involved, however, these monochromatic magnitudes may very well find numerous applications.

For a number of years red magnitudes have been under consideration and have been investigated at a number of observatories—in particular at the Harvard College Observatory. For several reasons it is likely that, as time goes on, red magnitudes will become more and more important in some fields of photometric work. Red light suffers less extinction in passing through our atmosphere than blue or yellow light; it appear to be less affected by seeing changes than light of shorter wave lengths; most important of all, it is less absorbed by the obscuring clouds in our galaxy than blue light. Before red magnitudes can be used to their full advantage, however, they must be standardized; a consistent body of data on absolute magnitudes and colors, the luminosity function, and so forth, must be established for red magnitudes as it has been for photographic and photovisual magnitudes. For this to be accomplished most readily, all observers working in the field must agree on a certain system, an effective wave length and zero point on which all will work. It would seem that the subject of red magnitudes could, with profit, be discussed in a preliminary way with regard to the choice of an effective wave length and an international set of standards at the forthcoming meetings of the International Astronomical Union. It should then be possible to present at the next following meeting recommendations as to the effective wave length and zero point that should be adopted, and possibly to present a provisional set of standards.

Probably no single detail in photometry is more important than that of working on a standard system with regard to scale, effective wave length or color, and zero point. This is true not only for red magnitudes as mentioned above, but also for photographic and photovisual magnitudes. Each observer, in order to have his observations have their full value, must reduce them to the international system, or provide the means for doing so. If he does not do this, his observations, regardless of the amount of time and labor he expended on them, are of greatly reduced value, for they cannot properly be combined or compared with other observations. If observations made on some non-standard system are combined with data on the international system, the results obtained will be affected with systematic errors, and wrong conclusions are almost certain to result.

The problem of placing observations on the international system may be solved in one of two ways: the observer may make his observations with an instrument (*i.e.*, with a proper telescope-filter-plate combination) that gives results that are directly on the international system; the observer may determine color indices for the stars whose magnitudes he has determined, and from these determine corrections to apply

to each star to convert his system to the international system. In general, the corrections required to place any magnitudes on the international system are proportional or nearly proportional to the color indices of the stars concerned. In order to make any set of magnitudes have its full value these corrections must be determined, or the data for determining them must be given. This point should not be overlooked by future observers; it has, unfortunately, been too often neglected by past observers.

The field of astronomical photometry is one of very great extent. Within its area are included sections of almost all other fields of observational astronomy; nearly every observational astronomer has been, is, or will be at some time during his career, a photometric observer. Many of the areas of the field have apparently been well worked over, but under the examination of the careful observer, there is scarcely one of these areas that will show no room for improvement. There is much unexplored territory in the field; a whole new region has been opened up by the recent developments in electronics. Throughout the entire field of photometry there have never been greater opportunities for exploration and discovery, nor greater promises of rich rewards of new knowledge for the careful investigator.

LICK OBSERVATORY, APRIL, 1946.

Sweeping the Skies from Stromlo

By LEN BARSDELL

Australia, in keeping with its geographical location, its clear skies and sunny days, is taking its rightful place in the world of astronomy.

Dominating a ridge of hills about seven miles from Canberra, Federal Capital of Australia, is a pine-covered peak known as Mount Stromlo. There is nothing very unusual about this mountain. Its rugged slopes are camouflaged with pines and a few stunted gums, and in general appearance it looks like any other rise in this country of ranges and ridges—except, perhaps, for its summit which is flat and rectangular. Here, some 2,650 feet above sea level is a compact group of buildings that comprise the Commonwealth Observatory.

Located about 100 miles from the coast in the centre of a Commonwealth forestry reserve, Mount Stromlo offers unique opportunities for solar research. It is free from the glare of city lights and the grit and smoke-haze of industrial areas, and its position enables scientists to have a clear, unobstructed view of the heavens. This freedom from glare and haze is essential to present-day accuracy.

Mount Stromlo Observatory, begun in 1923, completes a chain of such institutions around the world. Apart from the benefits Australia

derives from the work of this Observatory, its importance lies in the fact that scientists can now keep the sun continuously under observation.

Study of the sun and its influence on the ionosphere—a belt around the earth of varying characteristics, vitally important in short-wave radio transmission—is an essential phase of the observatory's work. The program is long, involving endless calculation and collection of data. It is an accepted fact that the Commonwealth Observatory has the longest series of automatic records of the ionosphere (one every 15 minutes) in the world. During the war information about this work was of necessity strictly "off the record," but it can now be revealed that statistics passed on to the Services proved of incalculable value.

Ironically enough, the impetus of war speeded the development of the Observatory, which, until 1939, existed with a skeleton staff for one purpose only—the study of the sun. Today, the Commonwealth Observatory is pursuing the whole field of astronomical research, in addition to which it provides Australia with an accurate time service.

The idea of forming an institution for the study of the southern heavens was first mooted in 1907, but it was not until three years later that the Mount Stromlo site was selected. Investigations were conducted in many parts of Australia and covered thousands of miles of territory. It was generally conceded that, of all the places inspected, Mount Stromlo offered possibilities eclipsing all others. It had the necessary altitude and distance from the sea, good building sites, and a water supply to suit all needs. In 1911 a temporary observatory was erected "high up among the rocks and lizards, miles from anywhere," according to an early report of the mountain top, and the Government Astronomer of Victoria was deputed to test the suitability of the site. After two years' observations he reported favourably. In March, 1914, the Administrator of the Federal Territory foreshadowed the erection of an up-to-date observatory at Mount Stromlo at a cost of £250,000, with annual running costs of about £20,000. This gave rise to much favourable comment and some criticism.

A small but vocal minority expressed the fear that too much attention towards the astronomical field might lead to a cult of star-gazers. Others, more practical, suggested the proposed observatory might be able to advise farmers of weather conditions 14 days ahead and of approaching floods so that they could get their stock to higher ground. The more cynical, however, asked what influence sunspots might have on the rise and fall of governments, and suggested this might furnish an obscure and fascinating field of research. Despite this cross-section of opinion, it was generally recognized that a Commonwealth Observatory would benefit not only Australia but the world of science.

Interest was heightened by the announcement that members of the British Association for the Advancement of Science, some of whom

FIGURE 1

A BIRD'S-EYE VIEW OF THE COMMONWEALTH OBSERVATORY ON MOUNT STROMLO, SHOWING IT ALMOST SURROUNDED BY A FORESTRY RESERVE OF PINES.

were astronomers, would visit Australia in August, 1914, to advise upon the possibilities of solar research. Unfortunately, 1914 was to be a fateful year for Australia and the world. The British delegation arrived shortly after the outbreak of the first world war to find Australia preparing to assist Britain in resisting the enemy. Undaunted, the visiting scientists, who included the Astronomer Royal (Sir Frank Dyson), Sir Oliver Lodge, and the Director of the Astrophysical Observatory at Washington, D. C. (Mr. C. G. Abbot), waited on the Prime Minister, Mr. (later Sir) Joseph Cook, and emphasized the need for an observatory in Australia to cover the magnificent field of southen stars, which still awaited investigation from the astrophysical point of view. But neither public opinion nor the persuasive powers of the visiting scientists influenced the government. Australia was at war and money was needed for more urgent purposes. Both Britain and

America, however, continued to advocate an observatory in the Southern Hemisphere to link up with a chain of stations covering the northern field.

With the end of the war in November, 1918, the Lick Observatory of America made representations to establish its own research station in Australia, and sent out Professor Hussey to make preliminary investigations. He tentatively selected a site at the Canobalas Range at Orange, some 200 miles west of Sydney. His visit prompted certain amateur astronomers to suggest that Australia might assist America to build an observatory here. Nothing happened. The years were passing and still the Commonwealth had no solar observatory. In 1923 the observers on Mount Wilson, California, spoke of the need for a properly equipped solar observatory in Australia. The establishment of such an institution, they said, was of paramount importance because the sun could then be kept continuously under observation, which at that time was impossible. It was an Australian-born physicist, Professor Geoffrey Duffield, who held a Chair of Physics at Reading, England, who eventually turned the tide. His persistent advocacy decided the issue, and in that year the Commonwealth Government agreed to reserve Mount Stromlo for an observatory. The Lick Observatory thereupon abandoned its plans for active research work in Australia.

A committee of British astronomers, invited to appoint a director, chose Professor Duffield, who assumed his duties on January 1, 1924. High hopes were held for the success of the institution. Until then Mount Stromlo had been used almost solely as a look-out station for bush fires in the summer months. Henceforth, it was explained, scientists would use the mountain top as a look-out for the study of solar phenomena and spectroscopic research, and for the investigation of associated terrestrial phenomena. The project received the support of the British association for the Advancement of Science, the Interna-

FIGURE 2

THE COMMONWEALTH OBSERVATORY AND ADMINISTRATIVE BUILDINGS.

tional Astronomical Union, and scientific bodies in America, India, and Europe.

Professor Duffield, in his initial report on January 2, 1925, said: "As large a portion as possible of the apparatus required for the new instruments should be made in Australia. It is my earnest desire that we should take our place among the great observatories of the world.

"It is even possible that we may lay the foundations of a lens-making industry in Australia. This might have far-reaching importance in the event of our ever becoming isolated, and the men trained in our works might ultimately develop an industry which would make periscopes for submarines, range-finders, theodolites, field glasses, etc."

Such foresight! It was 15 years before the effect of Professor Duffield's statement bore fruit. Neglected until the beginning of World War II, the Commonwealth Observatory's rise to prominence has since been rapid. In 1940 optical work could not be done in Australia; even raw optical glass had to be imported. An optical munitions plant was established at the observatory during the war years and produced optical instruments equal to the best imported articles. These included prisms and lenses for all types of war instruments, periscopes, dial-sights, binoculars, telescopes, air sextants—all manufactured in Mount Stromlo's workshops with the precision of age-old craftsmanship.

Another phase of the Observatory's work today is providing Australia with an accurate time service. The determining of time is a very practical side of astronomy. Indeed, the principal observatory in the British Empire—The Royal Observatory at Greenwich, near London—was founded by Charles II in 1665 for the practical purpose of navigation, and to this day is maintained by the British Admiralty. Similarly, there is in Washington, D. C., the United States Naval Observatory.

For the same purpose—that is, to assist shipping—observatories were founded early in Australia's history at Adelaide, Melbourne, and Sydney, and were maintained by their respective State Governments.

The various Australian States, with the exception of Victoria, still maintain their own observatories, but the work of the Melbourne Observatory has now been taken over by the Commonwealth Observatory at Mount Stromlo, which, with the advantage of Australia's clear skies, has organized a time service comparable to those maintained by the great nations of the world. Every day the quartz clocks of the Postmaster-General's Department are put through on the land-line to Mount Stromlo and the "pips" recorded on a tape on which is also super-imposed observatory time. Margin of error is measured and then reported back to the P.M.G. Time accurate to 1/100th of a second is provided by clocks formerly used by the Melbourne Observatory, but even this is not enough. The P.M.G.'s Department wants accuracy to 1/1000th of a second so that radio frequency control, requiring the utmost precision, can be maintained in narrow bands without overlap.

Such accuracy is still beyond the power of astronomy.

The Observatory's work, quiescent until the beginning of World War II, was revolutionized and accelerated by the appointment of Dr. Richard van der Reit Woolley as Commonwealth Astronomer in 1939. This brilliant scientist has an international reputation as a writer on astrophysics. After studying at Capetown University, Dr. Woolley became the pupil of Sir Arthur Eddington, senior lecturer at Cambridge University's solar physics observatory. There he won a two-year scholarship which entitled him to study at Mount Wilson Observatory, California—leading astrophysical observatory in the world. After Mount Wilson he became Chief Assistant to the Astronomer Royal, Dr. H. Spencer Jones, at Greenwich Observatory. Under Dr. Woolley's inspiring leadership, the Commonwealth Observatory is taking its rightful place in the world of astronomy. "Australia's clear skies offer tremendous possibilities for research," he says. "In the past the Commonwealth Observatory has been hampered by lack of equipment. When this deficiency has been overcome, there is no reason why, five years after the end of the war, it cannot be the best in the British Empire, with perhaps the exception of Greenwich Observatory."

Undoubtedly, Australia's contribution to the field of solar research will be stepped up by the influence of Dr. Woolley. With a competent staff and modern workshops at his disposal, and the promise of new and essential equipment, the Commonwealth Observatory's future looks bright.

The Planets in January, 1947

By LELAND E. CUNNINGHAM

NOTE: The time employed is Central Standard Time unless otherwise indicated. The phenomena have been chosen and described for the North American continent, and especially for the United States. The basic data have been taken principally from the *American Ephemeris and Nautical Almanac*.

Sun. In January the sun will slowly move northward, but will still be more than 17 degrees south of the equator at the end.

Moon. The phases of the moon will occur as follows:

		C.S.T.
Full Moon	January 6	11 P.M.
Last Quarter	13	9 P.M.
New Moon	22	3 A.M.
First Quarter	29	6 P.M.

On the morning of January 16 an occultation of Jupiter by the moon will be visible throughout the North American continent. The times of immersion will range from 8 A.M., E.S.T., for the eastern seaboard, to 4 A.M., P.S.T., for the west coast. Jupiter will remain hidden for approximately an hour. Satellites IV and I will be occulted a little earlier, and III a little later; satellite II will be on or near the disk of Jupiter.

Evening and Morning Stars. Venus and Jupiter will be brilliant morning stars throughout the month. Saturn will be in opposition. There will be no visible evening star.

Mercury. Mercury will start the month west of the sun, but will be moving eastward more rapidly, and will overtake it on January 23, when it will be in superior conjunction. After that date it will slowly move out into the western sky, but will not get sufficiently far away by the end of the month to be visible.

Venus. Venus will continue its eastward motion, at first a little slower than that of the sun, and later a little faster than it. Their motions will be equal on January 27 at which time Venus will reach its greatest western elongation from the sun. It will remain a magnificent morning object.

Mars. Mars will be in conjunction with the sun on January 6, and throughout the month will be much too close to the sun for observation.

Jupiter. Jupiter will be a second splendid morning object; at first it will be close to Venus, but will rapidly fall behind it. It will be occulted on January 16, as described above.

Saturn. Saturn will be in opposition to the sun on January 26. Its high northern declination will make it a fine object for telescopic observation. It will continue its retrograde motion near the middle of Cancer.

Uranus. Uranus will continue its retrograde motion in the eastern part of Taurus.

Neptune. Neptune will be in Virgo, and at a stationary point.

Students' Observatory, Berkeley, California, November 14, 1946.

Occultation Predictions for January, 1947

(Taken from the *American Ephemeris*)

Date 1947	Star	Mag.	IMMERSION Greenwich C.T.	IMMERSION a	IMMERSION b	IMMERSION Angle E from N	EMERSION Greenwich C.T.	EMERSION a	EMERSION b	EMERSION Angle E from N
			h m	m	m	°	h m	m	m	°
	OCCULTATIONS VISIBLE IN LONGITUDE +72° 30′, LATITUDE +42° 30′									
Jan. 1	33 Ceti	16.2	2 4.1	−1.2	−0.3	67	3 13.1	−0.7	+0.1	231
2	38 Arie	5.2	20 11.7	−0.3	+1.8	58	21 13.2	−0.7	+1.7	243
10	46 Leon	5.7	9 44.2	−1.4	−1.4	112	10 53.6	−0.7	−2.0	311
16	JUPITER	−1.4	13 11.0	−3.2	+0.7	62	14 2.3	−0.9	−2.8	354
30	31 Arie	5.7	2 8.1	−1.0	+0.5	44	3 11.4	−0.7	−1.3	269
31	224 B.Taur *m*	6.1	21 50.3	−0.8	+2.0	53	23 0.4	−1.6	+1.1	258
31	227 B.Taur	5.9	22 31.8	−0.9	+2.1	45	23 41.5	−1.9	+0.5	267
	OCCULTATIONS VISIBLE IN LONGITUDE +91° 0′, LATITUDE +40° 0′									
Jan. 1	33 Ceti	6.2	1 37.9	−1.4	+0.9	49	2 54.7	−1.3	+0.2	240
10	46 Leon	5.7	9 24.1	−1.2	−2.1	147	10 33.9	−1.9	−0.8	276
16	JUPITER	−1.4	12 20.5	−2.0	+0.3	103	13 44.5	−1.5	−1.3	321
17	84 B.Scor	6.3	12 20.3	−3.3	+3.0	57	13 1.4	+0.5	−2.8	354
30	31 Arie	5.7	1 43.5	−1.3	+1.3	40	2 54.5	−1.4	−0.9	264
31	26 B.Taur	6.4	3 46.6	−1.2	+2.6	18	4 30.2	−1.0	−3.3	304
31	227 B.Taur	5.9	22 17.6	+0.1	+2.9	20	23 5.1	−1.9	+0.2	290

Date 1947	Star	Mag.	IMMERSION Greenwich C.T.	*a*	*b*	Angle E from N	EMERSION Greenwich C.T.	*a*	*b*	Angle E from N
			h m	m	m	°	h m	m	m	°
	OCCULTATIONS VISIBLE IN LONGITUDE +120° 0′, LATITUDE +36° 0′									
Jan. 1	33 Ceti	6.2	1 1.9	0.0	+3.3	3	1 53.1	−3.2	−0.3	282
1	*f* Psc	5.3	6 5.5	−0.8	+1.0	35	7 6.7	−0.7	−1.1	265
16	JUPITER	−1.4	11 57.0	+0.2	−1.6	165	12 51.5	−2.1	+1.8	259
17	15 G.Scor	6.4	13 5.4	−1.1	+0.7	103	14 21.0	−1.1	−0.5	313
30	31 Arie	5.7	1 7.2	+0.2	+4.1	0	1 52.0	−3.5	−1.5	292
31	26 B.Taur	6.4	3 3.4	..	..	3	3 44.2	−3.3	−3.1	303

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly, with the latitude, using *b;* apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

METEORS AND METEORITES

Meteor Notes from the American Meteor Society

By CHARLES P. OLIVIER, President

The weeks since the great Draconid shower of October 9 have continued to bring in reports from all parts of the country. Also thanks to Science Service I have received a copy of the reports from all the U. S. Army airfields, at home and abroad. The only trouble with this latter is that it is partially in code and that the names of the fields do not always convey to me where they are situated. Though a full analysis will eventually be made, for the moment, it seems that no appreciable shower was seen in Europe at any of our airfields, though it is true that at most of them cloudy or partly cloudy weather prevailed. In the Hydrographic Bulletins, U.S.N., so far nothing has appeared from ships at any distance from our eastern shores, hence I have no data which would permit an estimate of the longitude which marks the eastern limit of the shower. Such information will doubtless be available eventually.

Coming back to what is at hand, I now have some 400 reports, covering work by from three to five times that number of individuals. These I have arranged alphabetically by states and am beginning an analysis of the data. As there now seems no possible doubt that we have more information on this shower than was ever collected for a former one, I believe that it should be made as available as possible to scientists everywhere, as well as studied and worked over by me. Not only was the shower preceded by much excellent publicity but the papers carried in many cases clear instructions which were faithfully followed by observers. Also many were able to secure excellent photographs of the shower, hence we will have permanent records on a scale never before approximated. Only a few

of these latter are in my hands, but others write me of their excellent success and I hope eventually will send me prints for the permanent A.M.S. collection of meteor photographs. Hence we should have several determinations of the radiant based upon photography, whose accuracy is very high. A few of our regular members undertook to get the radiant by plotting, most did not as I really think that they were rather overwhelmed by the grandeur of the spectacle, and confined their activities to getting accurate unit rates, which indeed was most important. Still we have some determinations from plots by our better observers. These radiants will be published in these "Notes" when properly derived or checked.

Meantime it is my difficult task to condense our data so that their publication in an intelligible form is practicable. A beginning is made here following the form used in recent years for the Perseids. The table below contains this information: 1) state, station, and observer, also time used if reported or certainly known, 2) direction towards which watch was kept, 3) time when regular observations began, 4) time when regular observations ended, 5) the time of maximum intensity *for the interval covered* (unfortunately this often did not include the true maximum for the station due to the observer watching for too short an interval), 6) number of minutes observed, allowing for gaps, 7) number of meteors counted, 8) factor F for interval observed, 9) the average rate for whole period and, in same column and directly under, in ( ) the maximum rate, should it differ from the average, corresponding to the time given in 5), 10) the number of observers. With a full Moon and *perfect conditions* we take $F = 0.4$; some who were in cities or in areas where haze or clouds prevailed hence had F as low as 0.3, 0.2 or in extreme cases 0.1. Hence even for the best conditions anywhere on October 9, we consider that the rate for a perfect, moonless night would have been 2.5 times as great as that observed. In 9)—rates—where * occurs it means that the observer was unable to count the numbers he saw, there were so many. It has always been our custom to make no attempt to secure rates for more than one observer, as such rates are not comparable directly with our unit, which is the hourly number seen by one person. But for this shower an exception is made since even for a group the rate has a qualitative if not quantitative value. So, often, in 9) a number in ( ) may be followed in 10) by a number > 1, which indicates how many people aided in securing this group rate. Again, in the table only a line is often given to reports by outstanding observers which deserve a much fuller analysis. This I hope to do when the publication of this condensed table places me in a more favorable position for discussion. The same remark holds for reports from several colleges and high schools where classes of from 10 to 40 individuals reported separately, yet all in one group and sent in by one person. These also will receive fuller recognition in future "Notes." It is a matter of peculiar satisfaction that several good observations of long-enduring trains were secured, one over California at about 7:40 P.S.T. having most observations. It is even possible that I may have enough to compute the height of this object. Should any reader have information on this or any other train that lasted a minute or more, I beg that he write me without delay giving me the fullest particulars which he can on both meteor and train. Such newly reported trains will appear in the revision of my paper on that subject, now in process of preparation.

Station and Observer	Direction	Began	Ended	Max.	Min.	Met.	Fac.	Rate	Unc.	Obs.
Alabama CST										
Burmingham										
Cooper, B. Y.	N	7:08	8:21	8:21	50	93	0.2			2
								(234)		2
Cullman										
Whisenhunt, Miss M.	NW	8:30	8:40		10	37	0.4	222		1
Duncanville										
Hubbard, Miss N.	N	8:20	8:30		10	68	0.4	408		1
Fayette										
Junion II Sci. Class		7:30	9:40	9:40	130	1395	0.4			?
								(2100)		
Palmer, A. M.		8:30	8:39		9	30		200		1
Florence										
Griffith, G. P.	SW to NE	8:45	10:00	9:40±	75	2517	0.4			2
								(3180)		
Huntsville										
Harris, Miss L.	N	8:30	10:35	9:33±	125	396	0.4	190		1
Marion										
McCown, Miss A. L.		8:00	11:15	9:30±	105	519		297		1
								(484)		
Martin, Miss F.		8:00	11:15	9:30	105	549		314		1
								(518)		
Montgomery										
Heath, H. C.		6:20	10:20	10:05±	180	2157				10
								(1396)		
Nauvoo										
Scott, T.		6:40	10:15	10:05±	100	1007	0.4			1
								(1275)		1
Tuscaloosa										
Watson, L. C.	WNE to NE	9:50	10:40	9:58	50	525	0.3			2
								(1125)		
Arizona MST										
Coolidge										
Slater, B.		8:40	8:50		10	154	0.4	924		1
Valencia, D.		8:51	9:01		10	342	0.4	2052		1
Jerome MST										
Nitsch, R.		7:00	8:30		90	900	0.4			2
		8:00	9:00	8:45±	60			*		2
		10:00	10:15		15	0		few		1
		11:00	11:15		15	1		0		1
Tucson										
Abernathy, Mrs. M. D.		7:30	8:00		30	402		804		1
		9:35	10:05		30	111		222		1
Burlinson, M. A.	NxW	9:13	9:43		30	80	0.3	160		1
Arkansas CST										
Batesville										
Hood, G. W.		9:30	10:00		30	193		386		1
Clarksville										
Beach, I. T.		8:30	9:30		40	294				6
		9:35	9:45		10	42		252		1
		9:55	10:05	10:00±	10	460				3
								(2760)		3
Conway										
McHenry, M. J.	NW	8:55	10:02		67	300	0.2	268		1
				9:46				(400)		1
Hot Springs										
Maddux, R. C.	Z	9:20	9:50		30	276	0.3	552		1

Station and Observer	Direction	Began	Ended	Max.	Min.	Met.	Fac.	Rate Unc.	Obs.
Arkansas									
Mena									
Berry, R. M.	SW	7:35	9:10		40	60			?
West Fork									
Houghney, W. J.		8:00	9:00		60	30±			1
California PST									
Alameda									
Curren, T.		6:36	8:15	7:48	54	1798	0.4		3
								(4068)	3
Avalon									
Mattoff, Mrs. M.		7:30	8:30		60	257		257	1
Burbank									
Keene, T. A.	N, NW	7:00	7:25	7:22	20	130			?
								(648)	
Camarillo									
Striegal, Mrs. D. E.	NW	6:30	8:15		105	1458	0.4		1
				7:52				(1600)	
Encinitas									
Spruit, T. C.		7:42	8:03	7:44	6	257	0.4		2
								(2800)	2
Fawnskin									
Suebbert, J. C.		6:40	7:00		20	108	0.2		2
Fontana									
Cook, H. B.	N	7:30	8:00	7:45±	5	100+		1200	1
Glendale									
Sullivan, Miss J.	NW	6:30	8:45		80	615		461	1
Wolcott, R. E.		6:55	8:00		65	100+			1
				7:40±				(>1200)	1
Grass Valley									
Underwood, Mrs. J. B.		8:			?	300		?	1
Hermosa Beach									
Willis, Mrs. J. H.	NE	7:35	7:40			5			1
Inyokern									
Crow, E. L.	SW, S	6:27	10:16	7:36	31	454			1
								(2040)	1
Crow, E. G.	NE, E	7:32	10:16	7:36	21	267			1
								(1404)	1
Frasier, H.	N, S	6:45	7:05	7:00	20	262		786	1
								(906)	1
La Habra Heights									
Schrota, Miss R.		6:05	7:25		80	1400			?
								(1050)	
Long Beach									
Lompras, T.		6:25	8:00	7:45±		762		481	1
								(1108)	1
Los Angeles									
Leon, E. L.		7:00	9:00	7:48±				>1500	1
Smith, L. G.		6:25	8:00	8:00	4.8	134		(2820)	1
Wilson, Miss B.		6:30	7:30		60	319			2
								(319)	
		7:40	8:10		30	74		1442	1
San Fernando H. S.									
Brown, J. W.								3836	12
Midway City									
Armstrong, R. J.	W, NW	6:55	9:12	7:22	16	135		(850)	1
Mill Valley									
Press, H. N.	NW	7:25	7:28		3	104	0.4	2080	1

Station and Observer	Direction	Began	Ended	Max.	Min.	Met.	Fac.	Rate Unc.	Obs.
California									
Napa									
Christoffersen, N.		6:55	9:45	7:42	30	300		(1404)	1
Trathen, F.	NW	6:40	9:45	7:52	175	1413	0.4	(1476)	1
Palo Alto									
Cuthbertson, A. M.		7:30	8:00	7:45±	30		0.4	*	
Pasadena									
Davis, Miss D. M.	W	7:06	7:24		18	202	0.2	(673)	5
Jones, Mrs. M. E.	NW	7:15	7:20		5	55		(660)	?
Buddhue, J. D.	N	6:26	9:55	7:43	131	855	0.2	(1180)	1
								392	
Palms									
Young, Mrs.		7:00	8:30	8:00±	90	400+		(4000)	1
San Bernadino									
Seaward, J. R.	Z	7:00	8:15	8:00±	75	2050	0.4	1640	1
Roseville									
Wells, C. E.		6:50	9:20	7:50			0.4	*	1
Roscoe									
Ellerseid, Miss M. M.	N	7:40	7:55	7:52	10	666		3996	1
	S	7:40	7:55	7:52	10	519		3114	1
St. Helena									
Aske, Miss E. E.	N	7:45			?	357			1
San Anselmo									
Baker, L.	NW	6:50	7:00		10	110	0.2	660	1
	NW	7:55	8:05	8:00	10	242	0.4	1452	1
Santa Monica									
Rawlings, C. W.	NE	7:10	7:40	7:50	30	300		(*)	2
Santa Rosa									
Canby, Miss K.		7:15	8:15		60	5000			3
Sacramento									
Fogus, C. A.								*	1
Sonoma									
Peterson, Mrs. E. E.		8:00	8:05		5	141		(1692)	1
Stanford Univ.									
Spurr, W. A.		7:40	8:40		30	2145			2
								(7092)	2
Upland									
Green, Miss G.		7:45	7:50	7:45	6	193		(2250)	1
Vallejo									
McCleland, R.		7:00	8:00		60	466		466	1
Platt, A. L.		7:00	8:00		20	100+		300+	1
Mitchell, Mrs. N. C.		7:50	8:25	7:55	20	184			2
								(1142)	1
Walnut									
Bennett, D. J.		7:30			15				1
Whittier									
Hastings, F. A.		6:25	10:00	8:00	?			(3000)	1
Wilmington									
Gilbert, W. L.		7:25	8:20	7:58	30	603		1206	1
								(2028)	1
Yuba City									
Hurdle, Mrs. H. F.		6:30	8:30	8:00	120		0.2	*	?
U.S.S. Wantuck λ 119°, ϕ 33°									
Long, W. C.		7:15	9:00	7:40±	105		0.4	*	1
Colorado MST									
Alamoso									
Hastings, N. R.	W	8:00	9:30	8:53	90	?	0.4	(1500)	1

Station and Observer	Direction	Began	Ended	Max.	Min.	Met.	Fac.	Rate Unc.	Obs.
Colorado									
Denver MST									
Holmes, F. T.	W	6:33	7:44		20	292	0.2		2
Chamberlin Obs.	all	6:40	9:02	8:54	240	4631	0.3		13
								(2788)	
Bartlett, T. J.	SSW						0.3		1

Flower Observatory, Upper Darby, Pa., 1946 November 19.

Contributions of the Society for Research on Meteorites

Edited by FREDERICK C. LEONARD
Department of Astronomy, University of California, Los Angeles 24

The Report of the President of the Society for the Term 1941 June to 1946 September*

LINCOLN LA PAZ
Institute of Meteoritics, University of New Mexico, Albuquerque

The Bylaws of the Society (Art. 2, Sect. 2) require that "The President shall prepare, at the end of his term, a written report on the history, progress, and activities of the Society during his administration." Consequently, it is my duty at this time to render to the Society a report covering the interval 1941 June to 1946 September.

At the Eighth Meeting of the Society, held, like the present one, at Flagstaff and at the Canyon Diablo, Arizona, Meteorite Crater, in 1941 June, the following Officers were elected:

President:	Lincoln La Paz
Vice-Presidents:	F. R. Moulton, Charles P. Olivier, and L. J. Spencer
Secretary:	C. H. Cleminshaw
Treasurer:	L. F. Brady
Editor:	Frederick C. Leonard

Because of war-time travel restrictions on the meetings of learned societies, and the lack of accommodations and other conditions pursuant to total war and pseudo-peace, it has not been possible to hold a meeting of the Society for Research on Meteorites since 1941, and the aforementioned Officers have accordingly held tenure for the unprecedented period of 5 years and 3 months! During the latter part of this period, the Secretary was able to devote less and less of his time to the affairs of the Society, and, as a result, certain of his duties were assumed either by the President or by the Editor. This fact typifies the difficulties under which the administration of the Society has been carried on.

There can be no better way to survey the years just past than to discuss

*Read at the end of the Ninth Meeting of the Society, inside the rim of Meteorite Crater, near Canyon Diablo, Arizona, on the afternoon of 1946 September 10.

what the war has done to the Society and what the Society did during the war. The war years were difficult ones for all young scientific organizations, but particularly so for an *international* group like the Society for Research on Meteorites. On the one hand, travel restrictions precluded both field work and the annual meetings, which were held without a break from 1933 to 1941 and which had been of such great value in stimulating the growth of the Society. On the other hand, distressing losses, particularly of foreign members, occurred. Just before the outbreak of World War II—*i.e.*, on 1940 December 31—the Society had 133 members in good standing, representing 31 States and 13 foreign countries. Twenty-one (21) new members have been added during my term, but resignations *etc.* have cut into the membership, so that, at the present time, we have 110 members in good standing, including only 9 foreign members representing 7 countries. Over two-thirds of our loss of members occurred in our foreign component or among our younger members who were in service. In view of conditions existing abroad, it is difficult to hope for speedy re-installation of our lost foreign members. Membership drives in the United States were out of the question during such a national emergency as the one thru which the country has just passed, but probably they can soon be undertaken with some hope of success.

The question of what the Society did during the war is a less depressing one to consider. In the present "Buck Rogers" era of military research, notable contributions to the solution of problems of high importance have been, and are even now being made by members of the Society, at the Johns Hopkins Laboratory of Applied Physics, the New Mexico Proving Ground, the Headquarters of the Second Air Force, and the Aberdeen, Maryland, and White Sands, New Mexico, Proving Grounds, and elsewhere. Such contributions, dealing with ballistics at extreme altitudes and velocities, hyper-velocity impacts, distribution problems analogous to those earlier encountered in the study of meteoritic falls, and a variety of other subjects, carry high classification and are not now available for general distribution; however, it should be mentioned that letters of commendation and citations from the Commanding Generals of the various United States Army Air Forces and from the War Department have been received by several members of the Society. Such proof of the practical value of meteoritics in grim war and uncertain peace should not be overlooked. This aspect of meteoritical investigations was of prime importance in motivating the late Dr. James F. Zimmerman, the sixth President of the University of New Mexico, to create an Institute of Meteoritics at that University on 1944 June 17, and to appoint as the Director of that Institute, the President of the Society for Research on Meteorites.

One aspect of the founding of the Institute of Meteoritics of the University of New Mexico will be of particular interest to all the members of the Society. The publication difficulties of the Society are well known. Dr. Leonard, our Editor, has done wonders with the limited space available to him in POPULAR ASTRONOMY; but a medium for the publication of longer papers, monographs, and treatises is clearly needed. Precisely such a medium was arranged for during negotiations between Dr. Zimmerman and your President in 1944. A new series of meteoritical monographs, entitled *University of New Mexico Publications in Meteoritics,* has been instituted, and the first such publication, the valuable and scholarly *Catalog of Provisional Coördinate Numbers for the Meteoritic Falls of the World,* prepared by the Editor of the Society, Dr. Frederick C. Leonard

(who is a Research Associate of the Institute), is now in press. All costs of this new series in meteoritics are borne by the University of New Mexico.

In 1945 September, and again at the meeting of the American Association for the Advancement of Science in St. Louis, Missouri, in 1946 March, the Society for Research on Meteorites gave official expression to its views concerning the vigorously debated question of federal subsidization of scientific research. At the request of Dr. Howard A. Meyerhoff,* a copy of the questionnaire of the Association on this issue was sent by your President to all of the American members of the Council of the Society, and the replies received were tabulated and made available to Dr. Meyerhoff's committee. I have been asked by Dr. Meyerhoff to express his appreciation of the valuable cross-section of scientific opinion thus made available to him and his colleagues. Later, at the St. Louis meeting, your Representative in the Council of the Association participated in the long and heated deliberations that preceded the action finally taken by the Council of the senior American scientific organization. The import to our Society of this matter of "federal-aid-to-science" legislation can be inferred from the fact that investigations in meteoritics and closely allied fields now being carried out under the direction of members of the Society for Research on Meteorites have been subsidized to the extent of several hundred thousand dollars! The meteoriticist will long ponder with mixed emotions the fact that it took the waste and tragedy of a second world war to force a realization of the value of meteoritical research!

Another matter discussed at the St. Louis meeting with Dr. Meyerhoff and other members of the Society for Research on Meteorites was that of the next joint meeting of our Society with the American Association. I had attempted to arrange for a joint session of the Society and Section E (Geology) of the Association at the 1946 March meeting in St. Louis, but, after considerable preliminary correspondence, I was forced to give up this plan. During the meeting in St. Louis, the Council of the Association voted to hold the next meeting of the Association in Boston in 1946 December. After sounding out the opinion of various members of the Society, I wrote Dr. Meyerhoff that it did not seem feasible to attempt a joint meeting of the Society with the Association in Boston. Under date of 1946 May 6, he replied as follows:

"In view of the wise decision not to have the Society for Research on Meteorites attempt the organization of a meeting for the Boston meeting of the American Association for the Advancement of Science next December, I thought you would be interested in the fact that we are seriously considering the scheduling of our December, 1947, meeting at Chicago. I am passing this information along in order that you may have maximum opportunity to consider what can be done, both in regard to possible joint meetings and also in regard to separate activities on the part of the Society at that time."

I am glad to bring this information from Dr. Meyerhoff before the Society at this early date, in order that every advantage can be taken of the possibility of holding a joint meeting with the Association in as central a location as Chicago.

For obvious reasons, the work that the various committees appointed during my term could accomplish was held near a minimum. Nevertheless, in recognition of the very real handicaps under which the chairmen and the committee members have labored, a warm vote of thanks is due them.

*[An Administrative Secretary of the A.A.A.S. and a Councilor of the S.R.M.—Ed.]

In conclusion, I wish to express my appreciation to my fellow Officers and Councilors and to the members of the Society at large for their staunch support of the Society during what I hope will prove to have been its darkest years. I feel sure that the incoming administration can look forward to the same splendid coöperation that has meant so much to those now retiring from office.

The Specific Gravity of Meteoritic Iron*

JOHN DAVIS BUDDHUE
99 South Raymond Avenue, Pasadena 2, California

ABSTRACT

A study of more than 100 determinations of the specific gravity of siderites indicates that most of the specific gravities found are lower than that of pure iron and all are lower than that of pure nickel. This fact indicates that either (*a*) a large proportion of the determinations are in error or (*b*) the specific gravity of meteoritic iron *is* often abnormally low, possibly as a result of porosity. The specific gravity should increase with increasing nickel content, and there is some indication that it does. The supposition that the determinations are low because of porosity does not seem consistent with the idea that siderites are a part of the debris resulting from the destruction of a minor planet.

The specific gravity of pure iron is somewhat uncertain. According to *The Metals Handbook*,[1] the specific gravities of ingot, carbonyl, and electrolytic irons are respectively 7.866, 7.860, and 7.874, presumably at 25° C. The specific gravity calculated from X-ray measurements of the lattice constant is 7.865. Cold work can reduce the specific gravity to 7.792, or possibly less. According to Jordan and Swanger,[2] the specific gravity of pure cast-nickel is 8.907 at 23° C. Cold-worked nickel gave 8.901 at 25° C., and annealing raised this value only to 8.902. The specific gravity of nickel-iron alloys does not vary smoothly with composition, altho it probably does so below a content of about 23% nickel, when the value has risen from that of iron to about 8.18.[1a]

In a recent paper, I gave the average specific gravity of siderites by classes.[9] In calculating those figures I used only values that I had no reason to reject; nevertheless, in the light of the foregoing figures, it seems probable that the figures given previously were too low, particularly those for classes Og, D_1B, and P. A new study based on 116 determinations has been made. All of these determinations were carried out to 3 figures beyond the decimal point, in the hope that they would be the most accurate; nevertheless, it seems almost certain that some of them are erroneous. Seventeen (17), or 14.6%, of the 116 were as large as, or larger than, 7.865, while 2 more were nearly that large. The rest are summarized in Table 1.

Two (2) other determinations fell outside the range included in Table 1.

One possible explanation of the consistently low values of the specific gravity of meteoritic iron is that most of the determinations are in error. This supposition seems hardly likely, especially since errors should give high values as well

*Read at the Ninth Meeting of the Society, Flagstaff and Meteorite Crater, Arizona, 1946 September 9 and 10.

TABLE 1

Class Interval	No.	Percent	Mean		
6.900-6.999	1	0.8			
7.000-7.099	1	0.8	7.139		
7.100-7.199	2	1.7			
7.200-7.299	4	3.5			
7.300-7.399	8	7.0	7.333		
7.400-7.499	5	4.4	7.443		
7.500-7.599	14	12.3	7.536		
7.600-7.699	15	13.1	7.654		75.4%
7.700-7.799	23	20.2	7.755	50%	
7.800-7.899	34	29.8	7.852		
7.900-7.999	6	5.2	7.930		
8.000-8.099	1	0.8	.....		
	114	99.6	7.677		

as low ones. Another possible explanation is that the iron is somewhat porous. R. A. Daly[3] has given the following figures for porosity:

TABLE 2

Material	% Ni	—Specific Gravity— Measured	Calc.	Porosity
45 Irons (Si)	14	7.642	7.850	2.6%
17 Irons (Si)	5.8	7.644	7.860	2.7%
11 Ataxites (D)	14	7.702	7.90	2.5%

W. Leick obtained 7.4727 at 15° C. for the Linville Mountain, North Carolina, ataxite (D_1L). He attributed this low value to its porous nature.[4] For Shingle Springs, California (D_1Sh), he obtained 7.8943 at 21°.9 C., whereas the calculated value is said to be 7.9215.[5] For the ataxite of Botetourt County, Virginia (D_1B), he found 8.185-8.187, which values are among the highest ever reported for a siderite.[6] Silliman found 7.875 for a solid lump of Shingle Springs, and 8.024 for shavings.[7] It may be that the working coincident with planing the iron closed the pores that might otherwise have been present.

We are fortunate in possessing a series of 21 determinations of the specific gravity of different specimens of one and the same fall, all of which were made by the same investigator, O. W. Huntington;[8] moreover, the fall involved (Coahuila, Mexico) is a hexahedrite (H), which one would expect to be a particularly uniform type of siderite. These data are given in Table 3, but are not included in Table 1.

TABLE 3

"Butcher Iron"			"Santa Rosa"		"San Gregorio"		"Hacienda"
7.616	7.204	7.858	7.925	7.631	7.740	7.734	7.953
7.751	7.758	7.405	7.953	7.632	7.477	7.787	
7.836	7.831	7.727	7.826		7.555		
	7.867						
Averages		7.685		7.793		7.658	

Presumably Huntington used the same technique and skill in obtaining all of these figures, yet they vary almost as much as those in Table 1, altho the overall average, 7.717, is somewhat higher, chiefly on account of the work on "Santa Rosa." This fact seems to indicate that the specific gravity of masses, even of the same fall, varies from specimen to specimen.

If the nickel content of siderites is plotted against the corresponding reported specific gravity, there is no indication that the specific gravity increases

with the nickel content, altho it has been indicated previously that such an increase would be expected. It is interesting to note, however, that Leick's figure of 8.18 for the Botetourt County ataxite (D_1B), with 18% nickel, is about what would be expected of an iron with a slightly higher nickel content. If the determinations less than 7.600 are excluded, the following averages are obtained:

TABLE 4

Siderites (Si)	No.	Sp. Gr.
Nickel less than 10%	57	7.777
Nickel greater than 10%	21	7.840
Both of the preceding combined	78	7.794
Hexahedrites (H) (except Coahuila)	13	7.768
Coarse and coarsest octahedrites (Og and Ogg)	6	7.814
Medium octahedrites (Om)	22	7.810
Fine and finest octahedrites (Of and Off)	12	7.773
Nickel-rich ataxites (D_1)	12	7.850

Here there is apparent a general tendency for the specific gravity to increase with the nickel content, altho the finer octahedrites are completely at variance with that tendency. It may be said, perhaps, that the other octahedrites have practically identical specific gravities. The difference of 0.004 is probably not significant.

The hypothesis has been advanced by Daly[3] that meteorites are the smaller fragments that resulted from the destruction of a minor planet whose orbit lay between those of Mars and Jupiter, and that iron meteorites are pieces of the metallic core of that planet. The pressures in the interior of even a small planet, such as that postulated by Daly, must be enormous. From one point of view, the pressures would seem to prevent the formation of pores in the iron; on the other hand, it might be supposed that the occluded gases would tend to expand when the pressure is released by the disruption of the planet and might succeed in producing a slight porosity. This supposition seems doubtful, especially since the process could work only if the metal were supersaturated with gas at the prevailing temperature—and iron meteorites average only 2.4 times their volume of occluded gas. Twenty-one (21) samples of artificial iron of various kinds averaged 8.25 times their volume of gas, and one contained actually 55 volumes of gas. It follows that siderites are probably well undersaturated with gas, at least at ordinary temperatures, and probably at considerably higher temperatures, since artificial irons presumably acquire their gaseous contents near the fusing point. It appears, then, that, if the low values of the specific gravity of meteoritic iron are due to porosity, this fact is inconsistent with the hypothesis that they are the fragments of a disrupted planet.

Other apparently accurate determinations of the specific gravity of iron are as follows: ingot iron at room temperature, 7.887 (Tamaru), 7.858 (O'Neil); vacuum-fused electrolytic iron at 20° C., 7.8685 and 7.867 (Cross and Hill); pure iron annealed at 775° C., 7.8547 (Cross and Hill), 7.864 (Andrew and Honeyman), 7.871 (Levin and Dornhecker); a single crystal of iron, 7.8701 (Kaya).

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[6] E. Cohen, *ibid.*, pp. 47-9.
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Desiderata for a General or Comprehensive Catalog of the Meteoritic Falls of the World*

FREDERICK C. LEONARD
Department of Astronomy, University of California, Los Angeles

ABSTRACT

The following 10 "desiderata" for a general or comprehensive catalog of the meteoritic falls of the world are discussed in order: (1) coördinate number; (2) name; (3) class; (4) time of fall or find; (5) total weight; (6) number *etc.* of individual masses; (7) additional data for a multiple fall or a shower; (8) physical and chemical characters; (9) depositories; and (10) bibliography. A set of abbreviations, for words most often used in the description of meteorites, meteoritic falls, *etc.*, is recommended.

The most fundamental information concerning fallen meteorites and meteoritic falls would constitute the sum and substance of a general or comprehensive catalog of the meteoritic falls of the world. As far as my knowledge extends, no such catalog—comparable to, *e.g.*, Burnham's and Aitken's "General Catalogs of Double Stars," in their field—has ever been attempted. O. C. Farrington's monumental "Catalog of the Meteorites of North America, to January 1, 1909,"[1] is the closest thing to a comprehensive catalog of North American falls compiled up to that date, while G. T. Prior's admirable "Catalog of Meteorites . . . of the British Museum (Natural History)," published in 1923, together with its 2 appendices, issued in 1927 and 1940, respectively—the latter under the authorship of M. H. Hey—comes nearest to being a general catalog of the meteoritic falls of the world; but neither Farrington's nor Prior's catalog is—or was designed to be—precisely the sort of thing I have in mind.

There follows an enumeration of 10 items that, in my opinion, compose the real indispensables for the kind of catalog contemplated. It is hardly necessary to add—tho it is a remarkable fact—that, for scarcely a one of the nearly 1400 falls of the world now on record, could complete information be given under all of these 10 headings; nevertheless, as much information as is obtainable for each fall should be included under as many of the captions as possible, in the hope that, as time goes on, more and more data for each fall will become available under more and more headings.

It might be questioned whether the tenth and last item—the bibliography—should be incorporated in such a catalog, regardless of how comprehensive the catalog would be without the bibliography. It could be argued that the kind of bibliography proposed would constitute a formidable undertaking in itself and would be altogether too extensive a piece of work to form merely a part of any catalog. I am willing to concede that possibility, which would be, then, the only

*Read at the Ninth Meeting of the Society.

valid reason for omitting the bibliography from the catalog and establishing it on its own as a separate, independent project, second in importance only to the catalog itself.

Whether it would be feasible or advisable for any one person to essay the compilation of a catalog of this type is another question calling for serious consideration. In view of my own recent experience with our much less pretentious "Catalog of Provisional Coördinate Numbers for the Meteoritic Falls of the World,"[2] I may perhaps be pardoned for saying that I should hesitate to embark upon such an ambitious assignment as a general catalog without a staff of several competent research assistants—and plenty of otherwise free time! Possibly the project would be carried thru to completion best as a coöperative enterprise, under the auspices of some such body as the Committee on Catalog of this Society or the newly established Institute of Meteoritics of the University of New Mexico: I am inclined to think that it would.

Without further preliminaries, then, we may proceed with the recital of the 10 "desiderata" in question:

(1) *Coördinate Number.*—The coördinate number not only gives the longitude and the latitude of the place of fall, to the closest tenth of a degree, but also serves as a reference number for the fall, thus obviating the necessity of assigning to it an arbitrary or a serial number in the catalog. If the longitude and the latitude are known more accurately than to the closest tenth of a degree—if they have been determined to, *e.g.*, the closest minute or even second of arc—they should by all means be included, with the highest precision to which they are known, in addition to the coördinate number itself. Any other information (such as, *e.g.*, specific directions) that would at all assist in locating the exact position of the fall should be incorporated. I cannot emphasize too strongly the importance of knowing accurately the location of every fall—such knowledge is indispensable to the progress of meteoritics.*

(2) *Name.*—The *full* geographical—*i.e.*, common—name should be given, as it appears in, *e.g.*, Prior's, Hey's, A. L. Coulson's,[3] or our catalog.[2] It is recommended that, as in the "Catalog of Provisional Coördinate Numbers,"[2] the falls be inventoried alphabetically by their place names under the respective continents—plus Oceania and Miscellaneous—and nearby islands, countries, States, *etc.*, where they occurred. In an index to the catalog, entitled "Index of Falls and Synonyms," each fall, irrespective of its location, should be listed alphabetically, in conspicuous type, by the primary part of its common name—henceforth to be called, for short, the "primary name"—(*e.g.*, CANYON DIABLO), and the number of the page in the catalog on which the fall is described should be given. After, or under, the "primary name" and the page number, should be enumerated, in alphabetical order, but in less conspicuous type, each of the synonyms or "aliases" of the fall (if it has any: a large percentage of the falls, unfortunately, have!). Each of these synonyms should itself be listed alphabetically in the index and should be followed by a cross reference to the "primary name" of the fall (*e.g.*, *Arizona, v.* CANYON DIABLO). Such an index would evidently enable any fall

**Addendum to (1) Coördinate Number.*—A list of the coördinate numbers of all the falls of the world, arranged in the order of (algebraically) increasing longitude and latitude, together with the primary part of the common designation of each fall, would constitute a most useful and convenient appendix to the catalog, whereby any fall could be immediately identified from its coördinate number alone.

instantly to be found in the catalog, if either the "primary name" of the fall or any one of its "aliases" is known.

(3) *Class.*—The class, as accurately—*i.e.*, in as much detail—as this has been reported. It is recommended that the symbols used for designating the numerous classes, in what is essentially the Rose-Tschermak-Brezina system of meteoritic classification, be the same as those enumerated in the tables to which references are made in the accompanying note.[4]

(4) *Time of Fall or Find.*—The time of fall or find, as precisely as this has been recorded. It is highly desirable to know the time of an observed fall to the closest minute, or even second, and the time of finding an unobserved fall to the nearest day. The time as given in hours, minutes, and seconds should be invariably the *standard time in use at the place of fall,* and, in order to avoid any ambiguity, or an error even of 12 hours, this should be expressed as A.M. or P.M.

(5) *Total Weight.*—The total weight in kilograms or (if this happens to be less than 1 kilogram) in grams. This should be the accurate, combined or integrated weight of all known specimens of the fall.

(6) *Number etc. of Individual Masses.*—The number of complete masses or individual meteorites known to have been recovered from the fall. Whenever possible, the weights (in kilograms or grams) and the linear dimensions (in meters or centimeters) of at least the largest representatives of the fall should be tabulated.

(7) *Additional Data for a Multiple Fall or a Shower.*—In the case of a multiple fall or a shower—*i.e.*, technically, a fall consisting of 2 or more individual meteorites—the shape, dimensions (*i.e.*, lengths of major and minor axes in kilometers), and orientation on the Earth's surface (*i.e.*, azimuth or bearing of the major axis) of the area or field over which the shower took place, should be recorded; furthermore, the precise positions within the area of all recovered meteorites, both large and small, should be specified in as much detail as possible.

(8) *Physical and Chemical Characters.*—Any data of a physical or chemical nature regarding the fall, such as, *e.g.*, the specific gravity, composition—as determined either chemically or spectroscopically—*etc.*, of specimens, should be incorporated. Under this heading would come also any pertinent information of a mineralogical, petrographical, crystallographical, or metallographical character.

(9) *Depositories.*—A complete list of the depositories of all the important (*i.e.*, largest and otherwise interesting) representatives of the fall.

(10) *Bibliography.*—A full bibliography of the fall. This should include complete references to all the published writings on the fall, arranged either chronologically or alphabetically, by authors' names. The *original* announcement or description of every fall should be clearly indicated.

It is recommended that, in addition to the standard or conventional abbreviations to be found listed in any good dictionary, the following more or less special abbreviations, for words most frequently employed in the description of meteorites, meteoritic falls, *etc.*, be henceforth used, particularly in catalogs of falls:

ALPHABETICAL LIST OF ABBREVIATIONS FOR DESCRIBING METEORITES, METEORITIC FALLS, ET CETERA*

ab.—about
aft.—after
anal.—analysis or analyzed
asso.—associated
bef.—before
bet.—between
bib.—bibliography
ca.—circa
calc.—calculated
cat.—catalog(ed)
cen.—center or central
cl.—class, classification, or classified
C.N.—coördinate number
co.—county
com.—complete
comp.—composition
cr.—crater
D.C.N.—definitive coördinate number
dep.—department or depository
des.—described or description
det.—determined or determination
dim.—dimension
disc.—discovered or discovery
dist.—distance or district
div.—division
dtfl.—doubtful(ly)
dup.—duplicate
est.—estimate(d) or estimation
fd.—find or found
fl.—fall or fell
fln.—fallen
fr.—fragment
id.—identical, identified, or identity
ind.—individual
i. s.—in situ
kn.—known
lat.—latitude (symbol, l or ϕ)
loc.—located or location
lon.—longitude (symbol, L or λ)
mat.—material
mcal.—meteoritical
mcs.—meteoritics
me.—meteor
meas.—measured, measurement, or measuring
mec.—meteoric
men.—mentioned
mi.—meteorite
mic.—meteoritic
mid.—midnight
ms.—mass
mul.—multiple
mus.—museum
nr.—near
nt.—night
ob.—observation or observed
ox.—oxidized†
pc.—piece
P.C.N.—provisional coördinate number
phen.—phenomenon
pl.—place
pl. fd.—place of find
pl. fl.—place of fall
pn.—position
poss.—possible or possibly
pres.—preserved
prob.—probable or probably
prov.—province
pt.—part
ques.—questionable or questionably
recg.—recognized
recr.—record(ed)
recv.—recovered
reg.—regarding
rep.—report(ed)
sep.—separate
sev.—several
s. g.—specific gravity
shr.—shower
sing.—single
sp.—specimen
sub.—subdivision
syn.—synonym
ter.—territory
tl.—total
tm.—time
tm. fd.—time of find
tm. fl.—time of fall
tp.—township
undes.—undescribed
unkn.—unknown
unob.—unobserved
wt.—weight

Notes to the List of Abbreviations

*The abbreviation of a plural noun is the same as that of the singular form.

†As part of a classificational symbol, "x" instead of "ox." should be used for "oxidized"—*e.g.*, "Six" for "oxidized siderite."

References

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[2] *Univ. of New Mexico Publ. in Meteoritics*, No. 1, xiv + 54 pp., 1946.

[3] *Mem. Geol. Surv. India*, **75**, 1940.

[4] "Alphabetical List of Classificational Symbols for Meteorites," Table 1, *C.S.R.M.*, **3**, 223; *P. A.*, **53**, 466, 1945, and table on pp. ix-x, *op. cit.*, ref. (2), *ante*.

Simple Methods of Reading Coördinate Numbers Directly from a Map

GIBSON REAVES
Department of Astronomy, University of California, Los Angeles
Communicated by Frederick C. Leonard

When finding the coördinate numbers of meteoritic falls it is inconvenient to use any of the scales on a map, inasmuch as the degrees are seldom divided into tenths, but more often into 10-minute intervals. It is the practice—in determining latitude, *e.g.*,—to find the map-distance in millimeters, with the use of calipers, of the point of fall from the nearest parallel and to divide that distance by the distance between parallels differing by one degree. This procedure is both tedious and liable to error. A simpler method consists in employing a draftsman's short-cut: If two lines, A and B, represent parallels of latitude on a map, and if the latitude of a point X is to be expressed in tenths of the distance between A and B, place a scale in such a position that the zero (0) index of the scale falls upon A and the ten (10) index falls upon B; then slide the scale parallel to itself, and along the lines A and B, until the edge of the scale passes thru X; then read off the scale interval to X in tenths. In the case illustrated in Fig. 1, the latitude is

$$34°0 + 0°3 = 34°3.$$

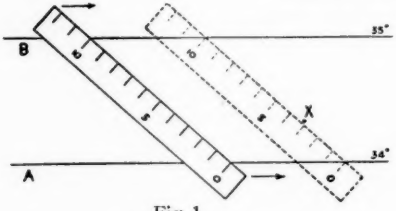

Fig. 1

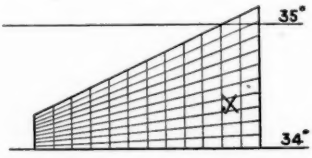

Fig. 2

SCALES FOR READING COÖRDINATE NUMBERS FROM A MAP

If it is necessary to read many coördinate numbers from maps having different scales, the scale illustrated in Fig. 2 may be scribed onto a thin piece of clear plastic. Each vertical line is divided into tenths by the lines that diverge from the left. To use this second scale, first calibrate it by placing it over the map and noting which vertical line has the same length as, *e.g.*, a degree of latitude; then place this vertical line—which is obviously divided into tenths by the radiating lines—thru the point in question and read off the perpendicular distance of the point, in tenths of the scale, from the nearest parallel.

The process of finding the longitude of the point X, and the inverse process of locating a fall on a map from its coördinate number are similar to those just described for reading the latitude.

Structure and Mass of Cometary Nuclei

Under the title, "Structure and Mass of Cometary Nuclei," an interesting paper by B. Vorontsov-Velyaminov, of the Sternberg Astronomical Institute, Moscow, U.S.S.R., appears in *The Astrophysical Journal*, **104**, 226-33, Sep., 1946. Following is the complete abstract of the paper:

"The different characteristics of the cometary nuclei are apparently contra-

dictory because of an improper terminology to describe the relevant facts. A terminology which avoids these difficulties is suggested and its physical meaning explained.

"Attention is drawn to the fact that the linear diameter of the solid nucleus can be determined only from the spectrograms, where the Fraunhofer spectrum is present; at the same time, the nuclei are too small to be measured on the spectrograms. Their reflecting surface can be calculated from the luminosity contributed by the Fraunhofer spectrum and the rate of evaporation, determined from the variation of the monochromatic luminosity of a comet. The mass of the nucleus can be calculated by estimating the loss of the gases, determined from the comet's luminosity and knowing the gas content of meteorites.

"The comparison of all such results obtained for Comets Halley and Peltier, 1936 *a*, leads to the following conclusions: The solid nuclei are some 25-60 km. in diameter and are composed of blocks some 160 m. in diameter, which are nearly in contact. The mass is 3×10^{19} gm. The evaporation of sodium and other problems also are discussed."

Meteoritical Abstracts

Attention is called to the valuable and extensive series of abstracts of papers (in all languages) on meteorites and tektites, contained on pp. 285-306 of *Mineralogical Abstracts*, **9**, No. 11, Sep., 1946, which is bound with the corresponding issue of *The Mineralogical Magazine*. Nearly all of these meteoritical abstracts are by the Editor of the *Magazine* and the *Abstracts*, Dr. L. J. Spencer, who is also one of the distinguished Vice-Presidents of this Society.

President of the Society: ARTHUR S. KING, Mount Wilson Observatory, Pasadena 4, California

Secretary of the Society: OSCAR E. MONNIG, 1010 Morningside Drive, Fort Worth 3, Texas

VARIABLE STARS

Variable Star Notes from the American Association of Variable Star Observers

By LEON CAMPBELL, Recorder

Current Notes on Variables: R And, 001838, is now at maximum brightness, between magnitudes 6 and 7; a rise of seven magnitudes in 90 days.

Alpha Cas, 003455, has a mean magnitude of 2.3, with a scatter between 2.1 and 2.5.

Gamma Cas, 005060, has a mean magnitude of 2.9, with a scatter between 2.6 and 3.1.

RX And, 005840, during the past three months has varied between magnitudes 10.7 and 13.0, with a mean interval between maxima of 7.6 days.

S Cas, 011272, is at maximum, magnitude 9.5, 610 days following the last observed maximum.

Omicron Cet, 021403, is nearing maximum brightness, brighter than 5.0, a rise of 4 magnitudes in 40 days.

SU Tau, 054319, is at normal maximum light, magnitude 9.7.

SS Aur, 060547, underwent a short-type maximum about JD 2432038, and a long-type maximum about JD 2432115.

Nova (RR) Pic, 06346*2*, is at magnitude 10.7, very slowly fading.

Nova Pup, 0808*35*, is at magnitude 10.8, very slowly fading.

Z Cam, 081473, during the past three months has varied between magnitudes 10.3 and 13.5, with a mean interval between maxima of 28 days.

S Aps, 14597*1*, is at normal maximum, magnitude 10.2, with evidence of a possible dip in brightness at JD 2432060 to magnitude 11.2.

R CrB, 154428, appears to be again decreasing in light. It was reported by Messrs. Rosebrugh and Cilley to be at magnitude 8.0 on JD 2432138.

Nova (T) CrB, 155526, is at magnitude 9.6, and slowly fading from secondary maximum at magnitude 8.0 in July last.

Alpha Her, 171014, has steadily increased in brightness from magnitude 3.7 on JD 2432050, to 3.3 on JD 2432090.

Nova (RS) Oph, 1744*06*, has varied irregularly between magnitudes 11.5 and 12.3 during the past 100 days.

Nova (DQ) Her, 180445, has a mean magnitude of 13.1, with a scatter between 12.8 and 13.4.

R Sct, 1842*05*, underwent a minimum at magnitude 7.6 on JD 2432082.

Nova Aql, 184300, has a mean magnitude of 11.6, varying between magnitudes 11.0 and 11.9.

R Aql, 190108, the star with one of the shortening periods, was at maximum on JD 2432044, following the previous maximum by 294 days, indicating a further decrease in period.

RY Sgr, 1910*33*, is at maximum, mean magnitude 6.2, with considerable scatter in estimates, doubtless due to low altitude for northern observers.

Chi Cygni, 194632, has steadily decreased in brightness, from a maximum magnitude of 5.7 in May to the magnitude 12, early in November.

AB Dra, 195377, is varying between magnitudes 11.0 and 14.5, with a mean interval between maxima of 10 days.

SS Cyg, 213843, passed through maximum 354 on JD 2432075, one of the long-type, having attained magnitude 10.0 on the increasing side of the curve on JD 2432066, 75 days following the previous rise to maximum.

RU Peg, 220912, was at maximum, magnitude 10.0, on JD 2432121.

Z And, 232848, increased from magnitude 10.2 on JD 2432020 to magnitude 9.0 on JD 2432120.

Rho Cas, 234956, is now at nearly constant brightness, magnitude 6.1.

Personalia: The Association has lost by death in the past two months three of its outstanding members, Mr. Eugene H. Jones, of Goffstown, New Hampshire,

Dr. William L. Holt, of Amherst, Mass., and Dr. H. H. Clayton, of Canton, Mass.

Mr. Jones, an observer for over twenty years, had made an enviable record for himself in becoming an ace observer for several years in succession. Starting out with a small 2½-inch refractor while living in Somerville, Mass., he gradually progressed to the use of a 6-inch refractor which he mounted in an observatory of his own construction, after retirement from the Edison Company to Goffstown. There it was that he spent many a hot, as well as cold, night keeping track of several hundred variables, among which SS Cygni was his particular favorite. Not only was he an ardent amateur observer of the stars, but he could wield a paint brush in truly artistic manner, particularly in depicting sea and landscapes.

It is to be regretted that, during the last two years, he had to suffer from nearly total blindness and also from pernicious anemia. He was in his 83rd year at the time of his death.

Dr. Holt, who, it will be remembered, was the contributor of the one millionth observation to the AAVSO records, died in October following a serious operation. He had attended the AAVSO meeting at Cambridge only the previous week and had looked forward to transporting his telescope and his family to Arizona for the winter, where he hoped to make a real record of observing under those clear skies. Dr. Holt had become one of our best observers over a span of a dozen years.

Dr. Clayton was a member of the Advisory Committee of the Solar Division of the AAVSO. He died after a short illness on October 27, in his 86th year. A meteorologist of nearly 60 years' standing, he had attained an international reputation in his field. He was particularly interested, in later years, in the study of the relation of solar activity to the weather.

The month of September proved to be exceptionally clear over many of the observing stations, with the result that a total of 5,121 observations were contributed during October, one of the largest monthly totals since before the war. Outstanding contributors were Messrs. Fernald of Wilton, Maine; Chassapis of Athens, Greece; de Kock of Capetown, South Africa; the late Dr. Holt of Amherst, Massachusetts, and Peltier of Delphos, Ohio.

Observer	No. Var.	No. Ests.	Observer	No. Var.	No. Ests.
Ahnert, P.	33	189	Halbach	43	49
Ball	8	8	Hare	19	33
Bappu, M. K. V.	24	32	Harris	13	13
Bicknell	7	20	Hartmann	142	190
Bogard	5	8	Holt	134	311
Boone	28	28	Howarth	12	12
Bouton	7	9	Hukill	3	66
Buckstaff	21	72	Kearons	20	20
Buscombe	1	1	Itzigsohn	51	107
Chassapis	116	661	Kelly, M.	12	37
Cilley	30	106	Kitley	39	79
Darnell	1	5	Knott	2	2
Fernald	240	755	de Kock	91	349
Flower	5	8	Kohn	6	7
Focas	103	253	Koons	72	96
Garneau	16	20	Lovinus	4	4
Greenley	9	10	Luft	3	13
Guimont	6	6	Mallett	10	16

Observer	No. Var.	No. Ests.	Observer	No. Var.	No. Ests.
Meek	22	75	Sochard	2	2
Nadeau	102	123	Stahr	3	5
Oheim	34	40	Stone	3	3
Oravec	22	34	Swaelen	3	41
Parks	25	42	Thomas	5	7
Peltier	172	298	Upjohn	15	24
Plakidis	24	103	Wade	6	43
Raphael	24	142	Webb	24	25
Rayna	5	8	Weber	24	24
Reeves	2	2	Welker	41	81
Rosebrugh	16	237	Welles	9	15
Schoenke	14	18	Whitmarsh	5	9
Schroeder	1	1	Zirin	12	12
Seagraves	3	4	—		
Sill	68	68	64	totals	5,121

November 15, 1946.

Comet Notes

By G. VAN BIESBROECK

A cablegram received November 3 in this country announced the discovery of an unexpected comet by Bester in South Africa. The information was sent by Dr. Paraskevopoulos of the Bloemfontein Harvard Station as follows:

1946 November 1 at 20^h0 U.T. Magnitude 11
Right ascension $5^h\,1^m0$ Declination —38° 47′
Daily motion -3^m0 — 5′

At this low declination there was little chance of confirmation from this side of the equator. Yet a transparent sky on November 5 allowed observations both by the writer at the Yerkes Observatory and by Giclas at the Flagstaff Observatory as follows:

1946	α h m s	δ ° ′ ″	Mag.
Nov. 5.3336	4 49 28.4	—38 43 0	11
Nov. 5.4213	49 9.8	42 58	11
Nov. 6.4360	4 45 34.2	—38 43 28	11

The comet appeared as a fairly large diffuse coma with a slight central condensation. The object has evidently been well followed in the Southern Hemisphere. On November 12 the following parabolic elements computed by Bobone at the Cordoba (Argentine) Observatory were transmitted by the central bureau of telegrams at Harvard:

PARABOLIC ELEMENTS OF COMET BESTER

Perihelion	1947 January 22.475 U.T.
Longitude of ascending node	33° 14′
Node to perihelion	340 41
Inclination	109 33
Perihelion distance	2.5343 Astr. Units

The comet moves in a highly inclined retrograde orbit and remains far from the sun.

The following ephemeris computed by the writer shows the future course.

EPHEMERIS OF COMET BESTER

0^h U.T.	α h m s	δ ° ′	Distance to Sun	Distance to Earth	Mag.
1946 Nov. 28	3 22 38	−35 17.8	2.604	.939	10.7
Dec. 6	2 54 6	32 17.5	.586	1.960	10.7
14	29 36	28 39.8	.570	2.013	10.8
22	2 9 41	24 42.5	.557	.095	10.8
30	1 54 11	20 41.6	.547	.200	10.9
1947 Jan. 7	42 32	16 47.3	.540	.323	11.0
15	1 34 9	−13 5.6	2.536	2.457	11.1

While hardly changing in brightness the comet slowly moves northwestward through the constellations of Fornax and Cetus and will be conveniently located by the end of the year. But little activity is to be expected in this comet which remains at a great distance from both earth and sun.

The writer has little to report about the several faint comets, previously observed, that are fading towards the end of their visibility; difficulties in getting suitable photographic material have curtailed the observations. On October 27 comet TIMMERS was reduced to a 15 magnitude little coma; it will soon be out of reach. On October 22 comet GIACOBINI-ZINNER appeared as an 11 magnitude fuzzy spot near the ephemeris position given on page 420. It is now best situated for southern observers but also losing in brightness. On the same night, October 22, a search for comet SCHWASSMANN-WACHMANN 1925 II did not reveal anything brighter than magnitude 16 in the predicted position. The search should be continued with the help of the ephemeris given last month.

Williams Bay, Wisconsin, November 13, 1946.

General Notes

Dr. Paul D. Jose, associate professor of astronomy and assistant director of Steward Observatory at the University of Arizona, has resigned his post to accept a position as associate professor of mathematics at Washington and Jefferson College, Washington, Pa.

Mr. Leo W. Scott tendered his resignation as President of the National Capital Astronomers, Washington, D. C. This was his second term of office in that official capacity. Mr. Scott, who will accompany the National Geographic-Army Air Forces eclipse expedition to Brazil next spring, finds the pressure of other duties too arduous to permit his functioning as President for the remainder of the Association year. The Board of Trustees has appointed Miss Mabel Sterns to fill his unexpired term. Miss Sterns has long been active in the NCA, and has edited its publication, "Star Dust," since its inception.

The Rittenhouse Astronomical Society held its monthly meeting on November 8, 1946, in the Morgan Physics Laboratory, University of Pennsylvania. The speaker was Mr. Everett C. Yowell, of Rutherford Observatory, Columbia University, his topic being "Pulsating Stars."

Portraits of Five Nobel Prize-Winners at the Library of Congress

Portraits of the five American scientists who were awarded Nobel Prizes in 1946 and selections from their scientific writings will be displayed in the Library of Congress from November 19 through December 31. The exhibit may be viewed in the foyer of the Thomas Jefferson Room in the Annex Building of the Library.

The five scientists honored in the exhibit are:

Professor Percy W. Bridgman, of Harvard University, who was awarded a Nobel Prize in Physics for his work on high pressure;

Dr. J. H. Northrop, of Rockefeller Institute, awarded a Nobel Prize in Chemistry for his work on the chemistry of enzymes and viruses;

Professor H. J. Muller, of Indiana University, awarded a Nobel Prize in Medicine and Physiology for his work on the effect of X-rays on genes and chromosomes;

Dr. Wendell M. Stanley, of Rockefeller Institute, awarded a Nobel Prize in Chemistry for his work on the chemistry of viruses;

Professor James B. Sumner, of Cornell University, awarded a Nobel Prize in Chemistry for his work on enzyme chemistry.

The Cleveland Astronomical Society

Dr. Fred L. Whipple of the Harvard College Observatory addressed the November 8th meeting of the Cleveland Astronomical Society. His topic was "Meteors and the Earth's Upper Atmosphere."

Dr. Whipple explained how meteor trails are used in making estimates of the density and temperature of the air at altitudes not reached by more direct methods. He showed how the altitudes of appearance and disappearance, time interval between these two, and the light intensity distribution along the trail were used in arriving at the final conclusion. Other methods of estimating density and temperature at great altitudes were described. The velocity of sound increases with temperature. A sound wave front from a violent explosion traveling at a low angle to the horizontal plane will curve downward if it reaches a warmer layer of air above. It will thus return to earth. Observations of such returns and their distance from the source have been useful in locating warmer strata of air at great elevations. The reflections of radio waves from such zones and the use of radar were also discussed.

The conclusions arrived at by these various methods indicate that the atmosphere decreases in temperature from the surface to the stratosphere, some ten miles up, where it reaches a temperature of about —55° C. It remains fairly constant for some distance above this, through the stratosphere. The temperature then increases with height until it reaches close to the boiling point of water at 35 or 40 miles in the ozone layer. It then decreases again to less than —50° C. at about 60 miles up where the aurora begins. From here it increases again to the greatest heights at which estimates can be made.

On the following afternoon, November 9, Dr. Whipple lectured to the Ohio Neighborhood Astronomers on "The Goals of Photographic Meteor Studies." He described the equipment, methods, and results hoped for in their program in which they hope to pick up one meteor per hour.

Henry F. Donner.

Western Reserve University, Cleveland 6, Ohio.

Book Reviews

Norton's Star Atlas, Tenth Edition. (Messrs. Gall and Inglis, 13 Henrietta Street, London, and 12 Newington Road, Eddinburgh.)

The ninth edition of this work was mentioned on page 524 of Volume 51 (1943) of this magazine. That a new edition has appeared is an indication that the demand for this popular star atlas continues. The tenth edition is in practically all respects the same as the preceding one. The reviews we gave for the ninth edition and for earlier ones were very favorable. Those reviews apply equally to the present edition. The amateur could secure quite a thorough course in astronomy through a mastery of the information included in this volume. The constellation charts are excellent, and the descriptive material is very well chosen.

C.H.G.

Handbook of Chemistry (Sixth Edition), by Norbert A. Lange. (Handbook Publishers, Inc., Sandusky, Ohio. $7.00.)

The preface to this new edition, the sixth, of the Handbook of Chemistry bears the date of April, 1946. The preceding edition was reviewed in this magazine on page 207 of Volume 52 (1944). What was said there of the Fifth Edition might well be said here with emphasis of the Sixth Edition.

In examining the voluminous contents of this volume of 2082 pages one is astounded by the number and variety of items included in it. As stated in the former review, it would be very difficult to think of any phase of material which lends itself to tabulation that is not here included. While it is a Handbook of Chemistry, the 271 pages of mathematical formulae, from the simplest algebra formulae through integration formulae to probability and elliptic integrals, will be useful to anyone having any computations to perform.

As in the preceding edition, the mechanical aspects of the volume are excellent. It is durably and handsomely bound in flexible fabricoid of a rich red color. It lies open conveniently at any page. The publisher's dictum that every chemist, chemical engineer, physicist, pharmacist, engineer, patent attorney, librarian, manufacturer needs a copy of this veritable library of chemical and physical data on his desk seems to be fully justified.

C.H.G.

The Soochow Astronomical Chart, by W. Carl Rufus and Hsing-Chih Tien. 24 pp., 4to. (University of Michigan Press, 311 Maynard Street, Ann Arbor, Michigan. $2.50, postpaid in U.S.A.)

The Soochow Astronomical Chart, the original of which is in the Confucian Temple in that city, contains a star map and instructions for a future emperor in China, prepared in 1193 and engraved in stone in 1247. The complete translation, the first in English, is accompanied by a historical introduction and full commentary.

The star map contains 1440 stars joined in 313 asterisms, which in general conform with the ordinary oriental pattern, altho there is some idealization of names and forms to adapt for imperial use.

The text presents a system of political astrology to guide state affairs. It is based upon a natural philosophy in which the Great Absolute evolved into the

three primal essences, Heaven, Earth, and Man. The unity of this trinity enables the rational principle in man to interpret celestial phenomena in their intimate relationship to terrestrial affairs. So the Celestial Emperor obtained directions from the heavens to rule his people beneficently. This political science or philosophy was apparently very effective in fashioning Chinese state affairs for several centuries.

Of the editors and translators, Dr. Rufus* was Professor Emeritus of Astronomy at the University of Michigan and Mr. Tien is in charge of courses in the Chinese language and literature.

The Amazing Electron, by James I. Shannon, S. J. (Bruce Publishing Co., Milwaukee, Wisconsin. 1946. $4.00.)

This compact volume is a useful addition to any scientific library, for it is a simplified, but accurate and comprehensive, survey of the more important developments in physics since 1890. It is designed to present the general reader with a non-mathematical, but scientifically reliable, explanation of the physical principles involved in such modern technological wonders as X-ray, radio and television, the atomic bomb, and electron optics, all of which have developed as a consequence of "modern" physics. This broad field is concerned fundamentally with the individual and collective characteristics of sub-atomic divisions of matter, together with their relationship to the phenomena of energy radiation.

The author, by way of partial limitation, approaches his vast topic with an analysis of the fundamental role of the electron in recent scientific achievement. After laying a basic framework of a few elementary definitions, he enters briefly into an historical account of its discovery and evaluation as a unit of mass and charge, its role within the atom, and its relation to other sub-atomic particles. Subsequent discussion of the tremendously important properties of thermionic and photoelectric emission of free electrons, X-ray production, origin of atomic spectra, and radioactivity is correlated to the basic concept of the energy content and distribution within the atom. Various processes of nuclear bombardment are explained in introduction to the field of nuclear fission, and some of the problems involved in the utilization of atomic power are mentioned. Cosmic rays and the principles of vacuum tubes and electron optics are sketched. In the concluding summary, the author emphasizes the dual nature of the electron as a basic unit of mass and electric charge, and as a vehicle of energy, both potential and kinetic.

Throughout the book the author exhibits keen enthusiasm in his subject and presents it with a maximum of clarity. He has achieved a non-mathematical treatise of an essentially mathematical science without obscuring the concepts upon which it rests. Dignity of treatment is preserved in the logical development and the use of terminology which is standard in physics; however a complete and detailed glossary is appended for the assistance of the totally uninitiated. The well-chosen illustrations assist the author's lucid and scholarly style in bringing out the meaning of the text. The book should have great value in providing the eager layman with an understanding of modern physical principles, and might well serve as a stimulating and perspective review of the field for the physics student.

J.C.

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*Died September 21, 1946.